Load Allocation
For
Total Maximum Daily Load (TMDL)

Crooked Creek
Middle Salmon River – Chamberlain Creek Subbasin
17060207

Revised: December 2002

<u>WQ CONCERNS AT A GLANCE:</u>

Water Body of Concern:	**Crooked Creek**
Assessment Units:	**(ID17060207SL067_05, ID17060207SL068_02, ID17060207SL068_03, ID17060207SL068_04)**
Subbasin:	**Middle Salmon River-Chamberlain Creek**
Watershed Identifier:	**17060207**
Parameter of Concern:	**Temperature**
Key Resources:	**Chinook Salmon Steelhead Trout Bull Trout Westslope Cutthroat Trout Resident Rainbow Trout**
Uses Affected:	**Salmonid Spawning, Cold Water Biota**
Sources Considered:	**Legacy Effects from Historic Mining, Altered Riparian Condition**

WATERSHED DESCRIPTION

Crooked Creek is a tributary to the main Salmon River in central Idaho. Crooked Creek originates near the divide with the South Fork Red River (South Fork Clearwater River subbasin) below Elk City. The creek flows southwest for about 11 miles, then bends west for several miles, then flows southwest again for another eight miles before entering the Salmon River. Fifty-four percent of the Crooked Creek watershed is in the Gospel-Hump Wilderness (the lower half of the stream), while 2% is in private ownership. The remaining lands are in the Nez Perce National Forest. There are two large tributaries, Big Creek and Lake Creek, entering the middle reaches of Crooked Creek as well as numerous smaller tributaries throughout the watershed. The upper half of Crooked Creek is in mixed conifer forest communities. Below Big Creek, Crooked Creek enters an area of decreasing tree density. By the time Crooked Creek reaches the Salmon River, the landscape is predominantly grass/shrub communities with few trees (see aerial photographs in Appendix 6 for examples).

WATER QUALITY CONCERNS

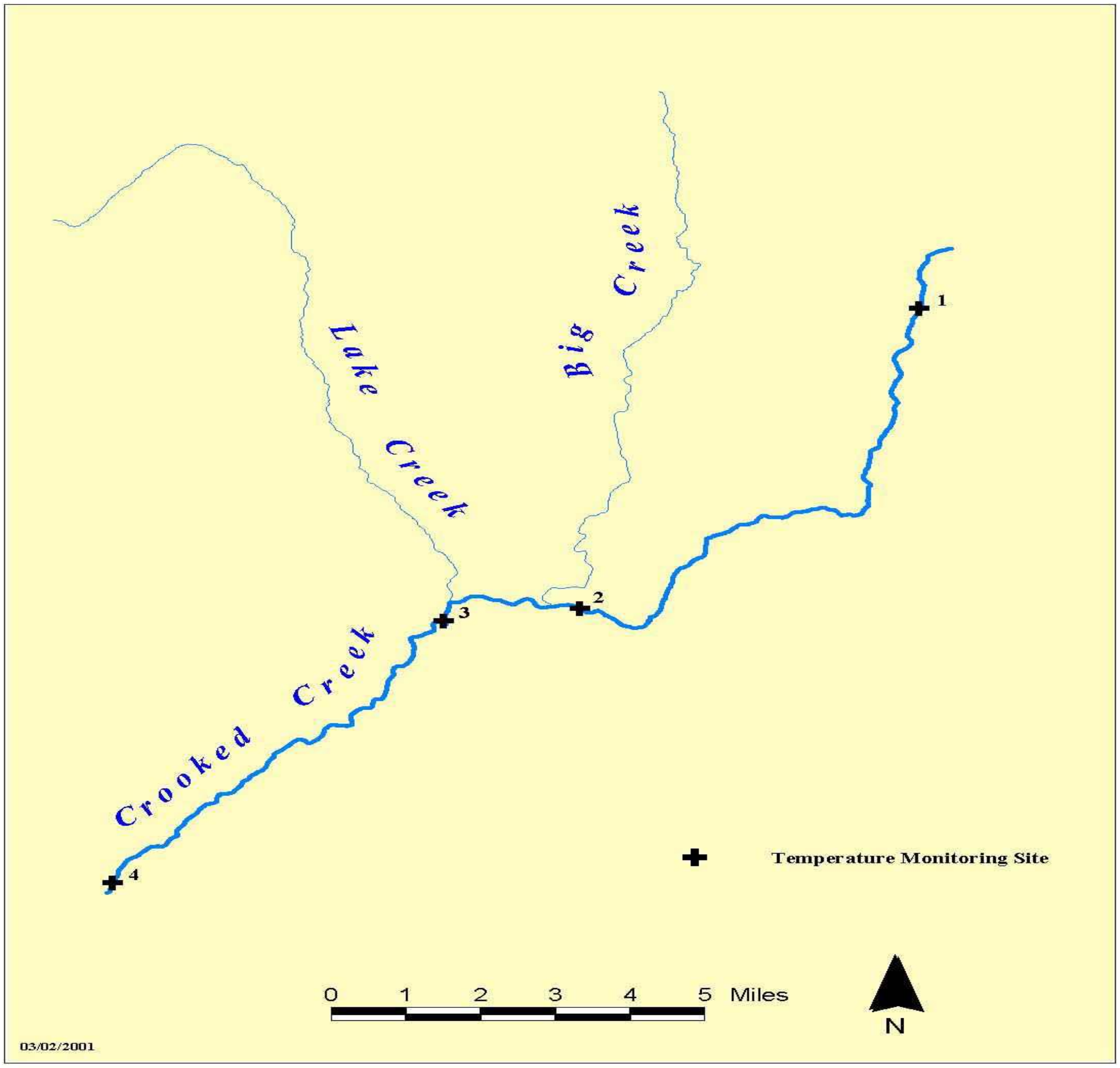
The problem assessment process determined that, although moderately high, sediment was not impairing aquatic life in this stream. However, it was determined that temperature measurements were high enough that salmonid spawning in upper Crooked Creek and bull trout spawning and rearing, if they occur in Crooked Creek, may be affected.

Temperature loggers have been placed in Crooked Creek at four locations every year from 1994 to 1999 (Map 12). These four locations include: 1) a headwaters site (Site 1), 2) a location below the town of Dixie and the Forest Service Dixie Work Center, but above the tributaries of Big Creek and Lake Creek (Site 2), 3) a location directly below Lake and Big Creeks (Site 3), and 4) a fourth location near the mouth of Crooked Creek (Site 4). The monitoring data show that the headwaters are relatively cool, but the water temperature increases rapidly through the impacted areas around Dixie. Water temperatures are cooled by entering the wilderness area and from the flow from Big Creek and Lake Creek. The water heats up again as it travels the remaining distance through the wilderness area to the mouth.

Elevations range from near 6000 feet in the headwaters to near 2000 feet at the mouth. We presumed that heating of the water as it passes through the wilderness area is a natural phenomenon, a result of atmospheric influences (air temperature and direct solar radiation). Aerial photos reveal that much of the wilderness area is open woodlands and grasslands (see Appendix 6).

Air temperature data for the Dixie area are presented in Appendix 5. From 1960 to 1990, Dixie reached an average maximum air temperature of about 78°F (25.5°C) in the summer time. With a standard lapse rate of 3.6°F (2°C) increase for every drop in 1000 feet of elevation (Aherns 1991), the mouth of Crooked Creek 3000 feet down may normally experience average maximum air temperatures near 89°F (31.7°C).

Map 12. Temperature monitoring sites on Crooked Creek.



A description of the location of the four sites follows:

- Site 1, approximately 5860 feet elevation, is located in the headwaters above Horse Flat Creek, which is 1.5 miles downstream from the origin of Crooked Creek at Dixie Summit.
- Site 2, approximately 5020 feet elevation, is 1.5 miles upstream of Big Creek and above the wilderness boundary. It is below the town of Dixie and a large open meadow with airstrip.
- Site 3, approximately 4240 feet elevation, is approximately 300 feet below Lake Creek tributary.
- Site 4, approximately 2100 feet elevation, is 0.25 miles upstream from the mouth of Crooked Creek.

Temperature Data Analysis

Surface water temperature data collected by the Nez Perce National Forest from Crooked Creek during 1994 to 1999 were used in this assessment. The data were collected from the four localities using temperature data loggers set to record hourly values. Raw data files were edited by deleting spurious air temperature values, days with less than 24 readings, and negative values. Mean and maximum statistics were calculated from the edited raw data and are presented in Table 17.

Table 17. Overall mean, peak maximum weekly maximum temperature (MWMT), and peak maximum weekly average temperature (MWAT) statistics calculated for the recording period (late June to early October) for each site and year.

Overall Mean Temperature °C				
Year	Site 1	Site 2	Site 3	Site 4
1994	8.7	11.3	11.1	14.3*
1995	7.4	10.1	9.0	12.3
1996	8.5	11.2	10.3	12.4
1997	7.6	8.9#	8.8	13.5
1998	10.0*	12.4*	12.1*	12.1
1999	5.6#	9.4	7.9#	10.3#
Average	8.0	10.6	9.7	12.5
Highest Maximum Weekly Maximum Temperature °C (MWMT)				
1994	14.1	21.5*	18.2*	22.4*
1995	12.7#	18.6#	15.3#	18.9
1996	13.5	19.5	15.6	18.8#
1997	12.9	17.2	15.6	19.1
1998	14.4*	20.2	17.0	20.9
1999	12.7#	18.7	15.4	19.6
Average	13.4	19.3	16.2	20.0
Highest Maximum Weekly Average Temperature °C (MWAT)				
1994	13.0*	16.7*	16.0*	19.5*
1995	10.7#	13.8#	13.2#	16.3#
1996	12.0	14.9	13.7	16.7
1997	11.5	14.1	13.9	16.9
1998	12.3	15.5	14.9	18.2
1999	11.6	14.3	13.7	17.0
Average	11.9	14.9	14.2	17.4

* Highest temperature for each statistic recorded at that site.
# Lowest temperature for each statistic recorded at that site.

Peak MWAT demonstrate consistently that 1994 was one of the warmest years and 1995 was one of the coolest in this data set. The other two statistics show this relationship less consistently. Overall means vary only a few degrees from upstream (Site 1) to downstream (Site 4). However, the average overall mean demonstrates an increase in temperature at Site 2 followed by a decrease in temperature at Site 3. This decrease in temperature at Site 3 is consistent throughout the data set. These data suggest that even the headwaters of Crooked Creek (Site 1) are fairly warm in the summer with peak MWMT averaging at 13.4°C.

Temperature criteria evaluation

Edited data sets were compared to Idaho temperature criteria for cold water aquatic life (22°C instantaneous and 19°C daily average throughout the monitoring periods), bull trout spawning (13°C instantaneous and 9°C daily average September through October at elevations over 4593 feet), bull trout juvenile rearing (12°C daily average June through August), and salmonid spawning (13°C instantaneous and 9°C daily average January 15 through July 15 and September through October). The edited data sets were also compared to the federal bull trout temperature criterion (10°C MWMT June through September). The number of days exceeding these criteria are summarized in Table 18 for each site and each year.

Table 18. Number of days exceeding temperature criteria at four sites on Crooked Creek.

Number of days in 1994 that Crooked Creek temperatures violated criteria.							
SITE	**22C[1]**	**19C[2]**	**13C[3]**	**12C[4]**	**10C[5]**	**9C-SS[6]**	**9C-BT[7]**
Site 1 Horse Flat Creek	0	0	0	15	65	15	1
Site 2 Halfway House	4	0	28	49	89	31	14
Site 3 Lake Creek	0	0	15	0	77	30	0
Site 4 Mouth	7	11	36	0	81	44	0
TOTAL # of Days	11	11	79	64	312	120	15

Number of days in 1995 that Crooked Creek temperatures violated criteria.							
SITE	**22C**	**19C**	**13C**	**12C**	**10C**	**9C-SS**	**9C-BT**
Site 1 Horse Flat Creek	0	0	1	0	62	18	6
Site 2 Halfway House	0	0	31	33	87	39	20
Site 3 Lake Creek	0	0	9	0	81	33	0
Site 4 Mouth	0	0	25	0	76	34	0
TOTAL # of Days	0	0	66	33	306	124	26

Number of days in 1996 that Crooked Creek temperatures violated criteria.							
SITE	**22C**	**19C**	**13C**	**12C**	**10C**	**9C-SS**	**9C-BT**
Site 1 Horse Flat Creek	0	0	0	3	46	3	2
Site 2 Halfway House	0	0	22	46	72	26	13
Site 3 Lake Creek	0	0	7	0	71	22	0
Site 4 Mouth	0	0	17	0	69	40	0
TOTAL # of Days	0	0	46	49	258	91	15

1 22C=cold water aquatic life maximum year round.
2 19C=cold water aquatic life daily average year round.
3 13C=salmonid spawning maximum to 7/15 and 9/15-11/15.
4 12C=bull trout daily average 6/1-8/31.
5 10C=bull trout maximum weekly maximum 6/1-9/30.
6 9C-SS=salmonid spawning daily average to 7/15 and 9/15-11/15.
7 9C-BT=bull trout spawning 9/1-10/31.

Table 18. Continued.

Number of days in 1997 that Crooked Creek temperatures violated criteria.							
SITE	**22C**	**19C**	**13C**	**12C**	**10C**	**9C-SS**	**9C-BT**
Site 1 Horse Flat Creek	0	0	0	1	45	11	11
Site 2 Halfway House	0	0	11	32	60	16	16
Site 3 Lake Creek	0	0	6	0	49	17	0
Site 4 Mouth	0	0	27	0	75	38	0
TOTAL # of Days	0	0	44	33	229	82	27

Number of days in 1998 that Crooked Creek temperatures violated criteria.							
SITE	**22C**	**19C**	**13C**	**12C**	**10C**	**9C-SS**	**9C-BT**
Site 1 Horse Flat Creek	0	0	2	16	62	20	18
Site 2 Halfway House	0	0	19	48	73	22	20
Site 3 Lake Creek	0	0	15	0	66	21	0
Site 4 Mouth	0	0	47	0	118	71	0
TOTAL # of Days	0	0	83	64	319	134	38

Number of days in 1999 that Crooked Creek temperatures violated criteria.							
SITE	**22C**	**19C**	**13C**	**12C**	**10C**	**9C-SS**	**9C-BT**
Site 1 Horse Flat Creek	0	0	2	1	62	8	0
Site 2 Halfway House	0	0	11	45	75	18	10
Site 3 Lake Creek	0	0	4	0	60	12	0
Site 4 Mouth	0	0	34	0	108	60	0
TOTAL # of Days	0	0	51	46	305	98	10

Average annual number of days that Crooked Creek temperatures violated criteria at each site.							
SITE	**22C**	**19C**	**13C**	**12C**	**10C**	**9C-SS**	**9C-BT**
Site 1 Horse Flat Creek	0	0	0.83	6	57	12.5	6.33
Site 2 Halfway House	0.67	0	20.33	42.17	76	25.33	15.5
Site 3 Lake Creek	0	0	9.33	0	67.33	22.5	0
Site 4 Mouth	1.17	1.83	31	0	87.83	47.83	0
TOTAL # of Days	1.84	1.83	61.49	48.17	288.16	108.16	21.83

Cold water aquatic life criteria (22C and 19C) were exceeded in only one (1994) of the six years of data. All other criteria were exceeded every year. The daily maximum salmonid spawning criterion (13C) included both spring spawning and fall spawning time periods. This criterion at Site 1 was exceeded only occasionally. At the other sites it was exceeded up to a month or more. The 12C and 9C-BT are state criteria for bull trout rearing and spawning, respectively. These criteria are applied to waters above 4593 ft. (1400 m) elevation. Thus, no violations are recorded for Sites 3 and 4 for these criteria. The 12C criterion is exceeded from zero to 16 days, with an average of six days at Site 1. At Site 2 this criterion is exceeded an average of 42 days. The 9C-SS and 9C-BT criteria reflect the differences between just the fall spawning period (9C-BT) and both spring and fall spawning periods (9C-SS). At Sites 1 and 2 the number of days exceeding criteria can double when both spring and fall spawning periods are considered. The 9C-SS criterion shows how spring and fall spawning temperatures faired at Sites 3 and 4, generally a month or more of violations. The 10C criterion is the federal bull trout criterion that applies to the entire creek during the summer months (June through September). It is the lowest temperature of all the criteria represented here that applies during the warmest time period of the year. Therefore, the 10C criterion reflects the maximum number of days in violation, averaging from 57 days at Site 1 to 88 days at Site 4.

The elevation change between Site 1 and Site 4 is about 3,731 feet. Over half (56%) of that change occurs between Sites 3 and 4 (Table 19). Surface waters tend to warm to a greater extent at lower elevations because air temperature is usually greater. However, the rate of change in water temperature should be proportional to the change in elevation, regardless of actual elevation provided that the water is flowing at the same rate and exposure is the same. Crooked Creek, however, has two large tributaries (Big Creek and Lake Creek) between Sites 2 and 3 that potentially contribute cooling water to Crooked Creek. And the gradient in the upper section is much lower than below Site 2.

Table 19. Amount of change between sites for numbers of days exceeding certain criteria (averages for period of record: 1994 to 1999).

Site	Elevation (feet)	Distance from Source (miles)	No. Days Exceeding 9^oC*	No. Days Exceeding 10^oC@
#1 – Horse Flat Creek	5860	1.5	13	57
#2 – Halfway House CG	5049	10.7	25	76
Change from #1 to #2	-811(22%)	+9.2(47%)	+12(34%)	+19(61%)
#3 – Lake Creek	4209	12.8	23	67
Change from #2 to #3	-840(22%)	+2.1(11%)	-2(-6%)	-9(-29%)
#4 – Mouth	2129	21	48	88
Change from #3 to #4	-2080(56%)	+8.2(42%)	+25(71%)	+21(68%)

*9^oC as a daily average first day of monitoring through 7/15 and 9/1 through 10/31.
@ 10^oC as a 7-day moving average of daily maximums during June 1 to September 30.

Table 19 shows rates of change for various parameters between sites. For example, the elevation change between Sites 1 and 2 is 811 feet or 22% of the total elevation change for the creek. The largest elevation change occurs between Sites 3 and 4 (56%). The distance traveled between sites is greatest between Sites 1 and 2 (9.2 miles). We have used two criteria in Table 19 to analyze rates of change in number of days exceeding criteria. We used number of days exceeding criteria as an indication of water temperature; in other words, cooler temperatures produce few numbers of days exceeding criteria, warmer temperatures produce more days exceeding criteria. The number of days exceeding a daily average of 9^oC is based on the salmonid spawning criteria that would normally apply to Crooked Creek in the spring to July 15 for rainbow and cutthroat trout and from September 1 to October 31 for bull trout. Table 19 shows the number of days exceeding 9^oC as a daily average during those time periods. The other criterion is the federal bull trout criterion of 10^oC as a 7-day moving average of the daily maximums. This criterion applies June 1 through September 30.

The 10^oC criterion shows that there was about an equal amount of change in number of exceeding days between Sites 1 and 2 (19 days) as compared to Sites 3 and 4 (21 days) despite a two-fold difference in elevation change under the same comparison (811 ft. versus 2080 ft.). This suggests that the creek between Sites 1 and 2 is warming more than it should based on elevation change alone. The 9^oC criterion does not show this relationship. However, this criterion was not applied during the warmest part of the summer between July 15 and September 1. In this case, the change in number of days exceeding 9^{o}C daily average between Sites 3 and 4 is about twice the rate of change between Sites 1 and 2, consistent with elevation differences. In avoiding the warmest part of summer, this criterion does not reflect exceedances during warmer air temperatures and perhaps direct solar inputs from the sun high in the sky.

Rates of Temperature Increase

Rates of warming were estimated from raw temperature data as well. The differences in overall recording period mean temperature, maximum weekly maximum, and maximum weekly average, each averaged for all years of data, were calculated for the stream reaches between monitoring Sites 1 and 2, 2 and 3, and 3 and 4. For example, an overall mean is calculated for the June to October recording period for each site for each year. The overall means for each year are then averaged to form a single overall mean for that site. To determine rates of change between two sites, the overall mean for the upper site is subtracted from the overall mean for the lower site. These differences were divided by the amount of change in elevation and reach length to obtain two rates of temperature change. These rates are temperature change per stream mile and temperature change per 1000 feet of elevation (Table 20).

Table 20. Temperature change as a function of stream miles and elevation.

Site 1 to Site 2: 9.2 stream miles, 811 feet drop in elevation, gradient = 88.3ft/mi.		
	Rate of change per stream mile	Rate of change per 1000 feet elevation
Change in overall mean	0.28^{o}C	3.2^{o}C
Change in highest MWMT*	0.64^{o}C	7.3^{o}C
Change in highest MWAT	0.33^{o}C	3.7^{o}C
Site 2 to Site 3: 2.1 stream miles, 840 feet drop in elevation, gradient = 394.4 ft/mi.		
	Rate of change per stream mile	Rate of change per 1000 feet elevation
Change in overall mean	-0.41^{o}C	-1.0°C
Change in highest MWMT	-1.46^{o}C	-3.7°C
Change in highest MWAT	-0.31^{o}C	-0.8°C
Site 3 to Site 4: 8.2 stream miles, 2080 feet drop in elevation, gradient = 252.4 ft/mi.		
	Rate of change per stream mile	Rate of change per 1000 feet elevation
Change in overall mean	0.34^{o}C	1.3°C
Change in highest MWMT	0.46^{o}C	1.8°C
Change in highest MWAT	0.39^{o}C	1.5°C

*MWMT = maximum weekly average of daily maximum water temperatures.
MWAT = maximum weekly average of daily average water temperatures.

Crooked Creek cools between Sites 2 and 3 because Big Creek and Lake Creek add flow, the stream turns westward and may receive more shading from the mountain ridge to its south, and there is an increase of riparian cover in the wilderness area. Thus rates of change are negative values. Between Sites 1 and 2 the gradient is the lowest (88.3 ft/mi or 1.7%) although this stretch is the longest distance (9.2 miles). Residence time is greatest between Sites 1 and 2.

Between Sites 3 and 4 the distance (8.2 miles) is similar to Sites 1 and 2, however, the gradient is substantially greater (252.4 ft/mi or 4.8%). The rates of change per stream mile are similar between the lower reaches and the upper reaches. The rates of change per 1000 ft. elevation between Sites 1 and 2 are at least twice the rates of change between Sites 3 and 4.

The stream reach between monitoring Sites 1 and 2 had the highest rate of temperature increase on an elevational basis. This reach also has the lowest gradient, slower residence time, and contains the most human disturbance, particularly the Dixie mining district, the town of Dixie, the airstrip near Dixie Work Center, and associated roads. The stream reach between monitoring Sites 3 and 4 is contained primarily in the Gospel Hump Wilderness. An area that was affected by some legacy human disturbance from grazing (and possibly mining) at one time, and presumably some disturbance from wildfire and current recreational activities. However, the rate of temperature increase between Sites 1 and 2 needs to be reduced to be comparable to the stream reaches between Sites 3 and 4.

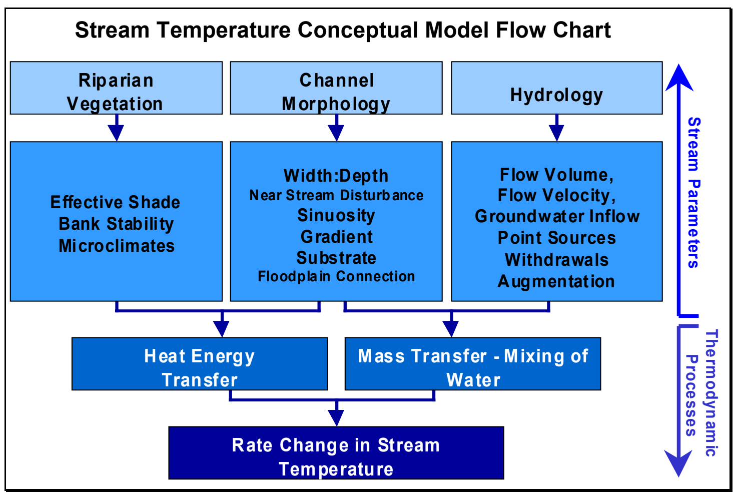
Temperature Summary

Temperature data suggest (see Table 18) that Crooked Creek may have slightly elevated temperatures naturally. The mouth of Crooked Creek on average has slight exceedances of cold water aquatic life criteria, consistent probably with the Salmon River itself in this canyon. Even in the headwaters of Crooked Creek stream temperatures are slightly greater than criteria on average creating a few days where salmonid spawning criteria are exceeded. Because salmonid spawning criteria are applied to a default time period for spring and fall spawning species, individual streams may have warmer temperatures near the end of the spring spawning period (mid-July) or at the beginning of the fall spawning period (September 1st) without seriously harming the actual spawning in the stream (i.e. fish spawn when the temperature is right and there is sufficient time to do so). Additionally, because we often consider average condition, there will be hot years when criteria are exceeded more often, and there will be cold years when criteria may not be exceed at all. In order to avoid confusion about criteria exceedances, the goal of this TMDL is to achieve the natural temperature regime in the stream by returning the effective shade to its natural condition. We anticipate that the natural temperature regime is cooler than the present condition, however, the natural temperature regime may not necessarily exclude temperature criteria exceedances.

Temperature TMDL – Effective Shade/Thermal Load Modeling

Effective Shade Overview - Description of Shading Processes (Provided by Peter Leinenbach, USEPA)

At any particular instant of time, a defined stream reach is capable of sustaining a particular water column temperature. Stream temperature change that results within a defined reach is explained rather simply. The temperature of a parcel of water traversing a stream/river reach enters the reach with a given temperature. If that temperature is greater than the energy balance is capable of supporting, the temperature will decrease. If that temperature is less than energy balance is capable of supporting, the temperature will increase. Stream temperature change within a defined reach, is induced by the energy balance between the parcel of water and the surrounding environment and transport of the parcel through the reach. The general relationships between stream parameters, thermodynamic processes (heat and mass transfer) and stream temperature change are outlined in the flow chart below.



Cumulative Effects

It takes time for the water parcel to traverse the longitudinal distance of the defined reach, during which the energy processes drive stream temperature change. At any particular instant of time, water that enters the upstream portion of the reach is never exactly the temperature that is supported by the defined reach. And, as the water is transferred downstream, heat energy and hydraulic processes that are variable with time and space interact with the water parcel and induce water temperature change. Further, heat energy is stored within this parcel of water and its temperature is the result of the heat energy processes upstream. This is commonly referred to as a cumulative temperature effect, where conditions at a site contribute to heating of an already heated parcel of stream water. The described scenario is a simplification; however, understanding the basic processes in which stream temperature change occurs over the course of a defined reach and period of time is essential.

Thermal Role of Riparian Vegetation

The role of near stream land cover in maintaining a healthy stream condition and water quality is well documented and accepted in scientific literature (Beschta et al. 1987). Riparian vegetation plays an important role in controlling stream temperature change. The important impacts that near stream land cover has upon the stream and the surrounding environment warrant listing.

- Near stream vegetation height, width and density combine to produce shadows that when cast across the stream reduce solar radiant loading.
- Near stream land cover creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity and lower wind speeds along stream corridors.
- Bank stability is largely a function of near stream vegetation. Specifically, channel morphology is often highly influenced by land cover type and condition by affecting floodplain and instream roughness, contributing coarse woody debris and influencing sedimentation, stream substrate composition and stream bank stability.

The warming of water temperature as a stream travels and drops in elevation (longitudinal heating) is a natural process. However, rates of heating can be dramatically reduced when high levels of shade exist and solar radiation loading is minimized. The overriding justification for a reduction in solar radiation loading is to minimize longitudinal heating. A limiting factor in reducing longitudinal stream heating is that there is a natural maximum level of shade that a given stream is capable of attaining.

Stream Surface Shade - Defined

Stream surface shade is an important parameter that controls the stream heating derived from solar radiation. Solar radiation has the potential to be the largest heat transfer mechanism in a stream system. Human activities can degrade near stream land cover and/or channel morphology, and in turn, decrease shade. It follows that human caused reductions in stream surface shade have the potential to cause significant increases in heat delivery to a stream system. Stream shade levels can also serve as an indicator of near stream land cover and channel morphology condition. For these reasons, stream shade is a focus of this analytical effort.

Shade is the amount of solar energy that is obscured or reflected by vegetation or topography above a stream. Shade is expressed in units of energy per unit area per unit time, or as a percent of total possible energy. In contrast, canopy cover is the percent of the sky covered by vegetation or topography. Shade producing features will cast a shadow on the water while canopy cover may not. In order to assess the ability of riparian land cover to shield a stream from solar radiation, two basic characteristics of shade must be addressed: *shade duration* and *shade quality*. The length of time that a stream receives shade can be referred to as *shade duration*. The density of shade that affects the amount of radiation blocked by the shade producing features is referred to as *shade quality*. Effective shade (**Figure 1**) is amount of potential solar radiation not reaching the stream surface and is a function of *shade duration* and *shade quality*.

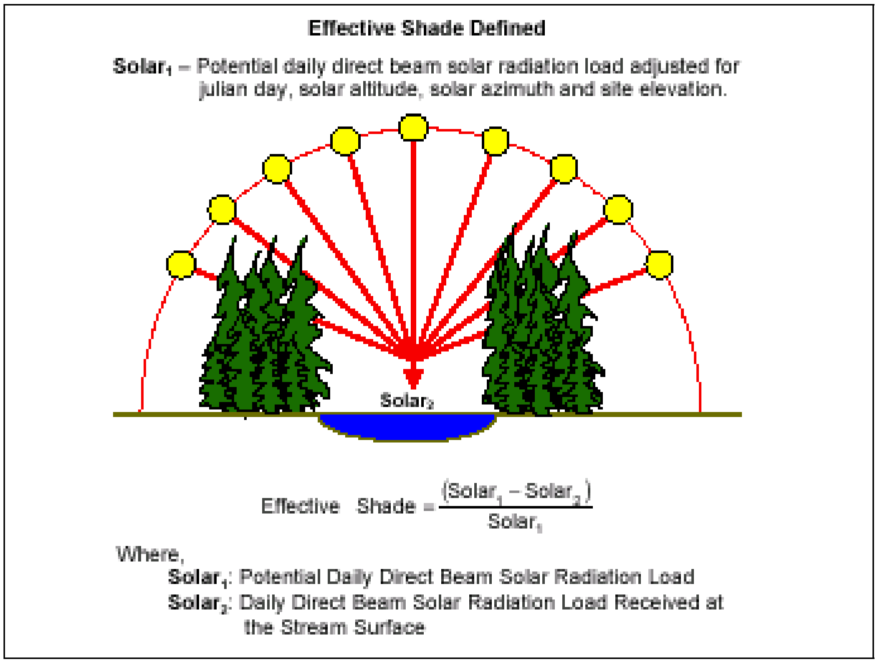


Figure 1. Definition of Effective Shade

In the Northern Hemisphere, the earth tilts on its axis toward the sun during summertime months allowing longer day length and higher solar altitude, both of which are functions of solar declination (i.e., a measure of the earth's tilt toward the sun) (**Figure 2**). Geographic position (i.e., latitude and longitude) fixes the stream to a position on the globe, while aspect provides the stream/riparian orientation. Near stream land cover height, width and density describe the physical barriers between the stream and sun that can attenuate and scatter incoming solar radiation (i.e., produce shade) (**Table 21**). The solar position has a vertical component (i.e., solar altitude) and a horizontal component (i.e., solar azimuth) that are both functions of time/date (i.e., solar declination) and the earth's rotation (i.e., hour angle measured as 15^{o} per hour). While the interaction of these shade variables may seem complex, the mathematics that describes them is relatively straightforward geometry. Using solar tables or mathematical simulations, the potential daily solar load can be quantified. The measured solar load at the stream surface can easily be measured with a Solar Pathfinder© or estimated using mathematical shade simulation computer programs (Boyd, 1996 and Park, 1993).

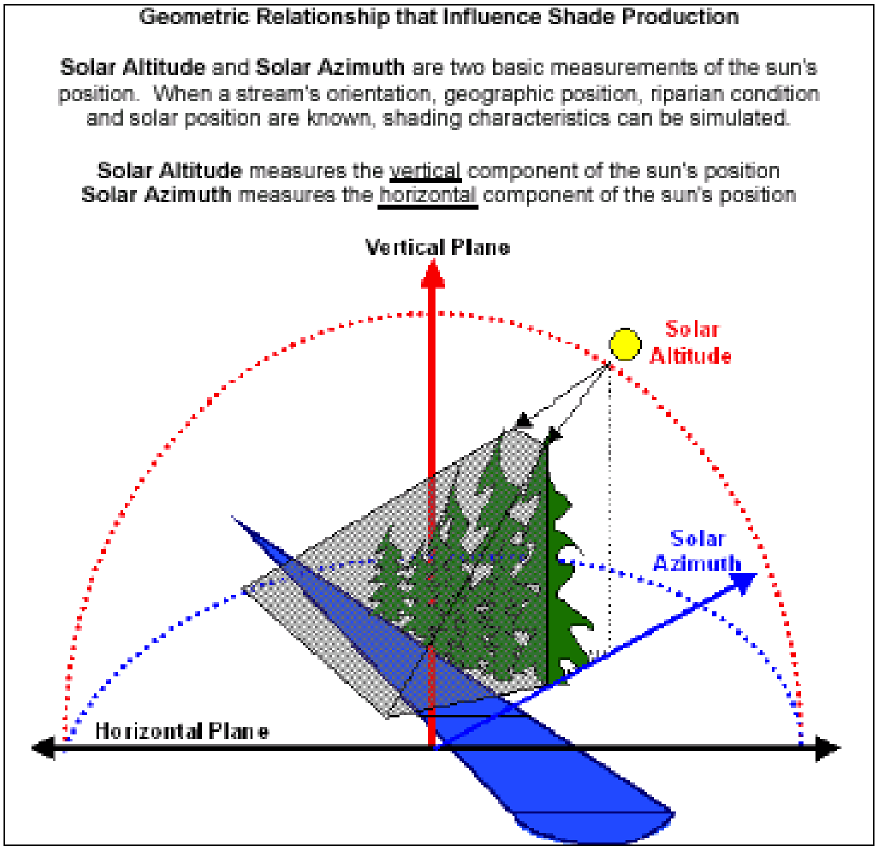


Figure 2. Parameters that Affect Shade and Geometric Relationships

Table 21. Factors that influence stream shade.

Description	Parameter
Season/Time	Date/Time
Stream Characteristics	Aspect, **Channel Width**
Geographic Position	Latitude, Longitude
Vegetative Characteristics	**Near Stream Land Cover Height, Width, and Density**
Solar Position	Solar Altitude, Solar Azimuth

bold type indicates factors that are influenced by human activities

System Potential Effective Shade - Defined

Primary factors that affect shade are near stream vegetation height and channel width (i.e. bankfull width). The maximum level of shade practical at a particular site is termed the "system potential" effective shade level. System Potential Effective Shade occurs when:

1. Near stream vegetation is at a mature life stage
   - Vegetation community is mature and undisturbed from anthropogenic sources;
   - Vegetation height and density is at or near the potential expected for the given plant community;
   - Vegetation is sufficiently wide to maximize solar attenuation; and
   - Vegetation width accommodates channel migrations.

2. Channel width reflects a suitable range for hydrologic process given that near stream vegetation is at a mature life stage
   - Stream banks reflect appropriate ranges of stability via vegetation rooting strength and floodplain roughness;
   - Sedimentation reflects appropriate levels of sediment input and transport;
   - Substrate is appropriate to channel type; and
   - Local high flow shear velocities are within appropriate ranges based on watershed hydrology and climate.

System Potential Land Cover

As listed above, "System potential land cover" is necessary to achieve "system potential effective shade," and is defined for purposes of the TMDL as "the potential near stream land cover condition that can grow and reproduce on a site, given: climate, elevation, soil properties, plant biology and hydrologic processes." System potential does not consider management or land use as limiting factors. In essence, system potential is the design condition used for TMDL analysis that meets the temperature standard by minimizing human related warming.

System potential is an estimate of the condition where anthropogenic activities that cause stream warming are minimized.

System potential is not an estimate of pre-settlement conditions. Although it is helpful to consider historic land cover patterns, channel conditions and hydrology, many areas have been altered to the point that the historic condition is no longer attainable given drastic changes in stream location and hydrology (channel armoring, wetland draining, urbanization, etc.).

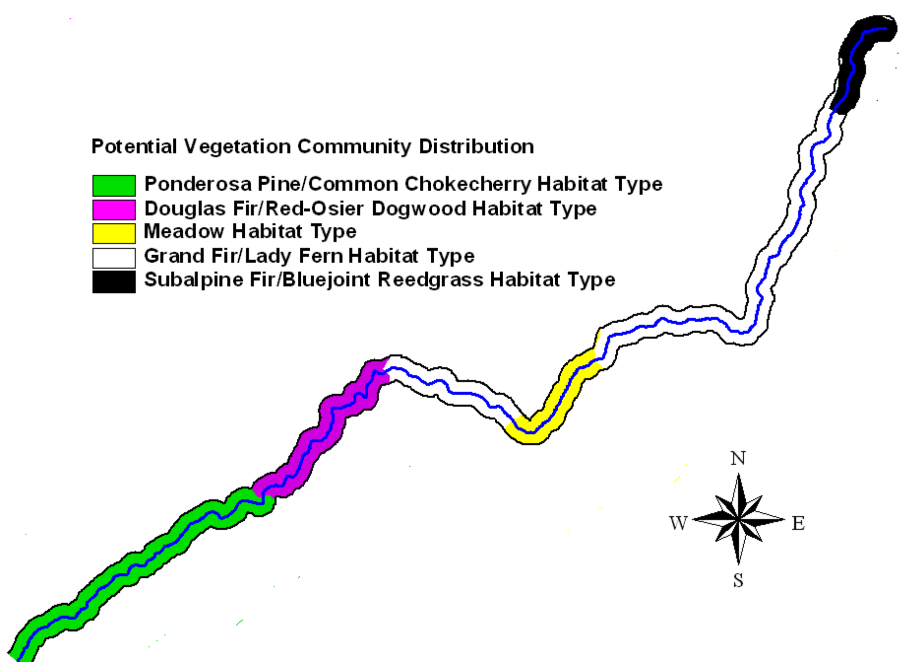
Potential Natural Vegetation

Spatial Distribution of Potential Natural Vegetation

Potential natural vegetation cover was estimated from habitat type descriptions provided by Hansen et al. (1995). We determined the riparian habitat types from Hansen et al. (1995) most likely to apply to Crooked Creek. Estimated habitat type conditions were intended to provide general representations of expected natural vegetation conditions throughout Crooked Creek. Estimated habitat types are not necessarily representative of ***current*** conditions around Crooked Creek.

The upper reaches (from Horse Flat Creek to Lake Creek, but not including the large meadow) were included in the grand fir/lady fern (*Abies grandis/Athyrium filix-femina*) habitat type. The very headwaters (above Horse Flat Creek) may be in more of a subalpine fir habitat type. Hansen et al. (1995) included a subalpine fir/bluejoint reedgrass (*Abies lasiocarpus/ Calamagrostis canadensis*) habitat type that may be representative. The large, grassy meadow near Dixie Work Center and airstrip was included in the Coyote willow (*Salix exigua var. exigua*) or tufted hairgrass (*Deschampsia cespitosa*) habitat type depending on whether or not the meadow was once willow dominated or grass dominated. The lower reaches (below Lake Creek) are either in the Douglas fir/red-osier dogwood (*Psuedotsuga menziesii/Cornus stolonifera*) habitat type or the ponderosa pine/common chokecherry (*Pinus ponderosa/ Prunus virginiana*) habitat type. **Figure 3** illustrates the spatial distribution of these vegetation communities along Crooked Creek.

Figure 3. Distribution of Potential Natural Vegetation Communities along Crooked Creek



Canopy Cover of Potential Natural Vegetation

For each habitat type, Hansen et al. (1995) provided average canopy cover, the range of canopy covers, and the constancy (% of sampling sites that contained the species) for species recorded in sampling plots. A weighted average canopy cover was calculated for each of the habitat types by summing the product of the average canopy cover and constancy for each tree species within each habitat type group. These calculations are presented in **Table 22**. It is important to note that these calculated cover values represent expected conditions based on the Habitat Type conditions presented above. These calculated canopy cover values should be viewed as a general representation of expected conditions within these habitat type groups. It must also be noted that, the Crooked Creek riparian area may contain other species not represented in this Table.

Table 22. A summary of species, canopy cover, and constancy for Habitat Types along Crooked Creek (from Hansen et al. (1995))

Grand Fir/Lady Fern Habitat Type	
Grand fir (*Abies grandis*)	30% average cover (100% constancy) = 30
Subalpine fir (*Abies lasiocarpus*)	3% average cover (20% constancy) = 0.6
Paper Birch (*Betula Papyrifera*)	3% average cover (20% constancy) = 0.6
Western Larch (*Larix Occidentalis*)	12% average cover (40% constancy) = 5
Spruce (*Picea spp.*)	20% average cover (60% constancy) = 12
Black Cottonwood (*Popuus trichocarpa*)	2% average cover (40% constancy) = 0.8
Douglas fir (*Psuedotsuga menziesii*)	9% average cover (60% constancy) = 5
Rocky mountain maple (*Acer glabrum*)	13% average cover (100% constancy) = 13
Mountain Alder (*Alnus incana*)	22% average cover (40% constancy) = 9
	Total weighted average cover = 76%
Subalpine Fir/Bluejoint Reedgrass Habitat Type	
Subalpine fir (*Abies lasiocarpus*)	32% average cover (100% constancy) = 32
Spruce (*Picea spp.*)	38% average cover (100% constancy) = 38
Whitebark Pine (*Pinus albicaulis*)	1% average cover (20% constancy) = 0.2
Lodgepole Pine (*Pinus contorta*)	17% average cover (50% constancy) = 9
Mountain Alder (*Alnus incana*)	2% average cover (20% constancy) = 0.4
	Total weighted average cover = 80%
Meadow Habitat Type	
Current	
Tufted hairgrass (*Deschampsia cespitosa*)	42% average cover (100% constancy)
Potential	
Coyote Willow (*Salix exigua* var. *exigua*)	82% average cover
Douglas Fir/Red-Osier Dogwood Habitat Type	
Narrowleaf Cottonwood (*Populus angustifolia*)	50% average cover (9% constancy) = 5
Quaking Aspen (*Populus tremuloides*)	21% average cover (30% constancy) = 6
Black Cottonwood (*Populus trichocarpa*)	44% average cover (43% constancy) = 19
Douglas fir (*Psuedotsuga menziesii*)	25% average cover (100% constancy) = 25
Red-osier dogwood (*Cornus stolonifera*)	11% average cover (43% constancy) = 5
Common chokecherry (*Prunus virginiana*)	10% average cover (43% constancy) = 4
	Total weighted average cover = 64%
Ponderosa Pine/Common Chokecherry Habitat Type	
Ponderosa pine (*Pinus ponderosa*)	27% average cover (100% constancy) = 27
Green Ash (*Fraxinus pennssylvanica*)	4% average cover (19% constancy) = 0.8
Common chokecherry (*Prunus virginiana*)	30% average cover (100% constancy) = 30
	Total weighted average cover = 58%

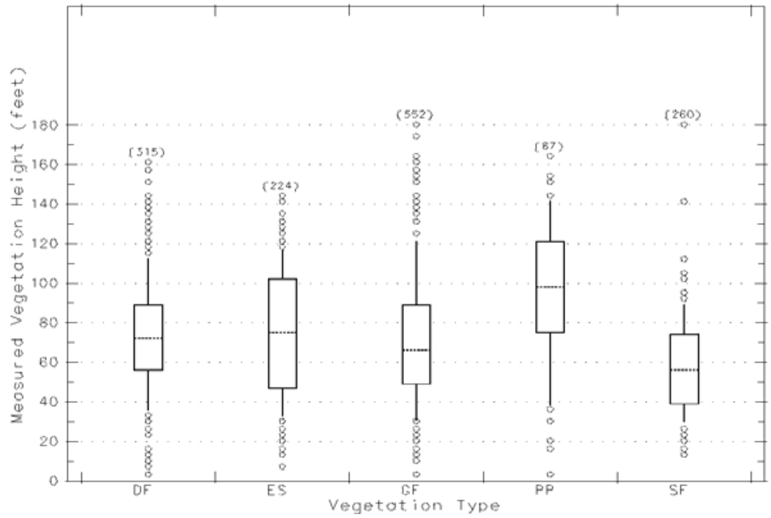
Height of Potential Natural Vegetation

Nationally recognized (Forest Service Fire Effects Information System) mature vegetation heights for each of these species are presented in **Table 23**. To provide a "reality check," tree heights presented in Table 23 were compared to tree height values measured within the Nez Perce National Forest (NPNF) (**Figure 4**), and they are reasonably comparable (i.e. the mature heights fall within the range of measured heights on the Forest). It is important to note that current conditions illustrated in **Figure 4** were developed from data that included all age classes (i.e., young to mature), and included "disturbed" vegetation, not just mature trees. Mature tree heights were chosen for the remainder of the analysis to provide an addition to the margin of safety.

Table 23. Mature Vegetation Height Condition
(from the USDA Forest Service Fire Effects Information System (www . fs.fed.us/database/feis))

Vegetation Type	Height Range (ft)	Suggested Value
Grand Fir (*Abies grandis*)	131 to 164	148
Engelmann Spruce (*Picea engelmannii*)	45 to 130	88
Douglas Fir (*Psuedotsuga menziesii*)	100 to 120 (var. glauca, R. Mnt. Interior).	110
Subalpine Fir (*Abies lasiocarpa*)	60 to 100	80
Ponderosa Pine (*Pinus ponderosa*)	90 to 130 (var. ponderosa, Pacific Ponderosa Pine).	110
Rocky Mountain Maple (*Acer glabrum*)	20 to 30	25
Red-osier Dogwood (*Cornus stolonifera* or *C. sericea*)	3 to 19	11
Chokecherry (*Prunus virginiana*)	3 to 19.5	12
Serviceberry (*Amelanchier alnifolia*)	3 to 26	15
Paper Birch (*Betula Papyrifera*)	70 to 80	75
Western Larch (*Larix Occidentalis*)	164 ("Typical")	164
Black Cottonwood (*Popuus trichocarpa*)	100 ("Common")	100
Mountain Alder (*Alnus incana*)	6 to 15	11
Whitebark Pine (*Pinus albicaulis*)	50 to 70	60
Lodgepole pine (*Pinus contorta*)	50 – 100 (var. latifolia)	75
Narrowleaf Cottonwood (*Populus angustifolia*)	60	60
Quaking Aspen (*Populus tremuloides*)	< 48	40
Green Ash (*Fraxinus pennssylvanica*)	66	66
Coyote Willow (*Salix exigua* var. *exigua*)	6 to 12	8

Figure 4. Measured Tree Heights in the Nez Perce National Forest (1989 – 1993)
(USFS Data, 2002)



Estimated Community Composition of Potential Natural Vegetation

Community composition dimensions for each of the Habitat Groups are presented in Table 24. This table shows the process by which dimensions for a composite shade producing vegetation are attained for each habitat type. The weighted average canopy cover from Table 22 is shown in the first column of numbers. These cover values for each species in the habitat type are converted to a relative proportion of the total cover in the second column of numbers. Vegetation heights from Table 23 are shown in the third column of numbers, and those heights are weighted based on relative cover to form the fourth column of numbers. Estimated overhang for the entire habitat type is then calculated as 10% of the total weighted height of trees (33% for shrubs). Thus, for example, the Grand fir type has a weighted average cover of 76%, a weighted height of 98 feet, and an estimated overhang of 9.8 feet. These values are used in the effective shade curve analysis to represent the composite shading potential of the all the species in the habitat type.

The average tree height condition within mature tree height range was included in subsequent effective shade analysis. Height values for several “Shrub” species were estimated in the upper range of expected values, except for the Meadow Habitat Group (i.e., Coyote Willow), which was allocated at the average value within the mature range of heights.

Table 24. Potential Natural Overstory Vegetation Composition along Crooked Creek						
PNOV Habitat Type	Overstory species	Weighted Ave. Canopy Cover (%)	Relative Proportion of Total (%)	Vegetation Height (ft)	Weighted Height (ft) (Proportions * Height)	Estimated Overhang (ft)
Grand Fir/Lady Fern	Grand Fir	30	39	148	58	
	Spruce	12	16	88	14	
	Douglas Fir	5	7	110	7	
	Rocky Mountain Maple	13	17	25	4	
	Subalpine Fir	0.6	1	80	1	
	Paper Birch	0.6	1	75	1	
	Western Larch	5	7	164	11	
	Black Cottonwood	0.8	1	100	1	
	Mountain Alder	9	12	11	1	
	Composite	**76**			**98**	**9.8**
Subalpine Fir/Bluejoint Reedgrass	Subalpine Fir	32	40	80	32	
	Spruce	38	48	88	42	
	Lodgepole Pine	9	11	75	8	
	Whitebark Pine	0.2	0	60	0.2	
	Mountain Alder	0.4	1	11	0.1	
	Composite	**80**			**83**	**8.3**
Meadow	Coyote Willow	82	100	8	8	2.6
	Tufted Hairgrass	42	100	2	2	0.8
Douglas Fir/Red-Osier Dogwood	Douglas fir	25	39	110	43	
	Red-Osier Dogwood	5	8	11	1	
	Common Chokecherry	4	6	12	1	
	Narrowleaf Cottonwood	5	8	60	5	
	Quaking Aspen	6	9	40	4	
	Black Cottonwood	19	30	100	30	
	Composite	**64**			**83**	**8.3**
Ponderosa Pine/Common Chockcherry	Ponderosa Pine	27	47	110	51	
	Green Ash	0.8	1	66	1	
	Common Chokecherry	30	52	12	6	
	Composite	**58**			**59**	**5.9**

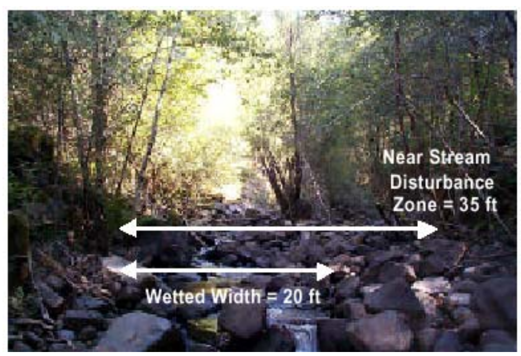
Shade Curves - Surrogate Measure

As presented earlier in this document, stream surface shade production is a function of geometric relationships between the sun's position and topography, near stream land cover and channel features. Stream surface shade at estimated potential natural vegetation community composition conditions (see Table 24 above) was simulated using computer software developed by Oregon Department of Environmental Quality8.

Over the years, the term shade has been used in several contexts, including its components such as shade angle or shade density. For purposes of the shade curves, shade is defined as the percent reduction of potential direct beam solar radiation load delivered to the water surface. Thus, the role of effective shade in this TMDL is to prevent or reduce heating by solar radiation and serve as a linear translator to the solar loading.

The non-point source assessment demonstrates that stream temperatures warm as a result of increased solar radiation loads, due to anthropogenic disturbance to near stream vegetation and channel morphology. A loading capacity for radiant heat energy (i.e., incoming solar radiation) can be used to define a reduction target that forms the basis for identifying a surrogate. The specific surrogate used is percent effective shade (expressed as the percent reduction in potential solar radiation load delivered to the water surface). The solar radiation loading capacity is translated directly (linearly) by effective solar loading. The definition of effective shade allows direct measurement of the solar radiation loading capacity.

As noted in Table 21, channel width is an important component of shade production. That is, it becomes progressively more difficult to shade a river with a particular vegetation conditions, as the channel width increases. Channel width is best described as the "Near-Stream Disturbance Zone" (NSDZ), which is defined for purposes of the shade curve as the width between shade-producing near-stream vegetation. Where near-stream vegetation was absent, the near-stream boundary was used, as defined as armored stream banks or where the near-stream zone is unsuitable for vegetation growth due to external factors (i.e., roads, railways, buildings, etc.). It is important to note that bankfull width and NSDZ are often similar.



Factors that affect water temperature are interrelated. The surrogate measures (percent effective shade and channel width) rely on restoring/protecting riparian vegetation to increase stream surface shade levels and reducing the NSDZ width (by reducing stream bank erosion and stabilizing channels), which will reduce the surface area of the stream exposed to radiant energy. Shade is more effective on narrow streams than on wider streams given the same flow of water at a given point because shadows cast by trees cover a greater percentage of the stream surface. Effective shade screens the water's surface from direct rays of the sun. Highly shaded streams often experience cooler stream temperatures due to reduced input of solar energy.

8 This shade calculator has been used by Oregon Department of Environmental Quality and Washington Department of Ecology during the development of temperature TMDLs during the past several years.

Effective shade curves were developed using vegetation conditions for Crooked Creek, as described in Table 24 (Figures 5 through 10). These curves are independent of location on the stream within a particular habitat type. Because effective shade is a measure of energy, a load in terms of Langleys per day can be directly calculated from this value. Given a measured or estimated channel width (e.g., NSDZ) and the directional aspect of a stream, the percent effective shade or the solar radiation loading can be estimated from the following graphs. It is best to have site-specific measurements of channel width and stream aspect (and vegetation for that matter) to produce an effective shade estimate at a specific location. In the case of Crooked Creek, because the site-specific information is based on interpretations of relatively coarse GIS-based information, the effective shade estimates are not precise for a particular location. To improve the estimates, actual channel width and aspect data would have to be collected in the field at some interval. The more frequent the interval, the more accurate the estimate.

As an example of how the effective shade curve works, let's say you have a location on a stream in a Grand fir habitat type where the aspect is NE (45^{o}), and the channel width (NSDZ) is five meters. Figure 5 shows that the squares line representing 45^{o} from North intersects the 5-m NSDZ grid where solar loading is about 58 Langleys/day and the potential effective shade is approximately 90%. In a similar stream in the same vegetation type, but with a 15-m wide channel, the potential effective shade is less than 75% (~156 ly/day solar loading). Actual effective shade may be less that these values at these stream sites due to disturbance. A solar pathfinder set up at the site could measure actual effective shade. Comparisons between actual and potential effective shade demonstrate how far from the target is the existing stream condition.

For the meadow habitat types (Figures 7 and 8), the shape of the curve is much different than forest based curves. Due to much lower vegetation height, a stream with a particular aspect will show rapid and substantial decreases in potential effective shade as the channel width increases. This is due to the fact that lower meadow vegetation cannot shade wide streams as well as trees can.

Figure 5. Effective Shade Curve – Application in Grand Fir/Lady Fern Habitat Type

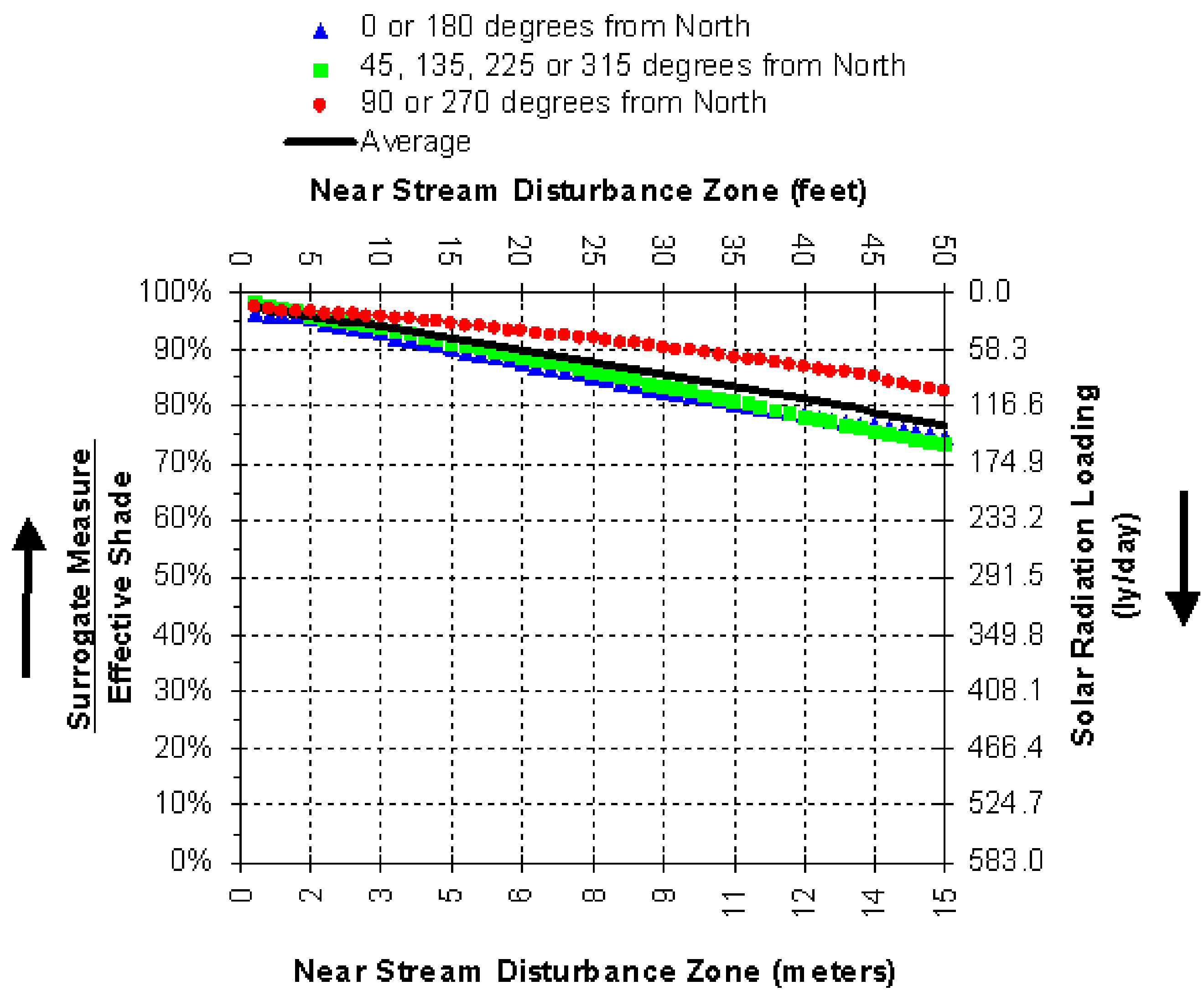


Figure 6. Effective Shade Curve – Application in Subalpine Fir/Bluejoint Reedgrass Habitat Type

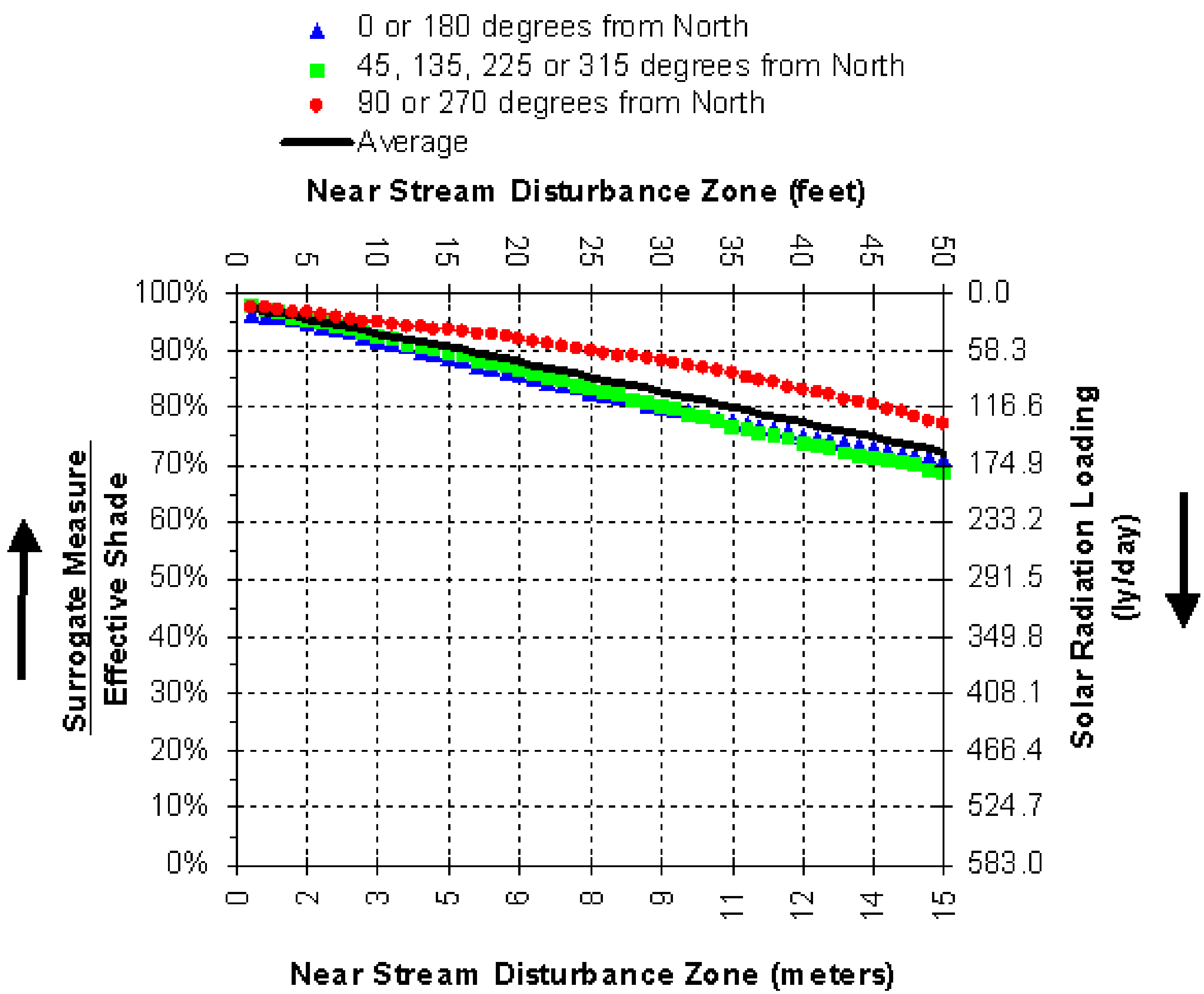


Figure 7. Effective Shade Curve – Application in Meadow Habitat Type - Coyote Willow

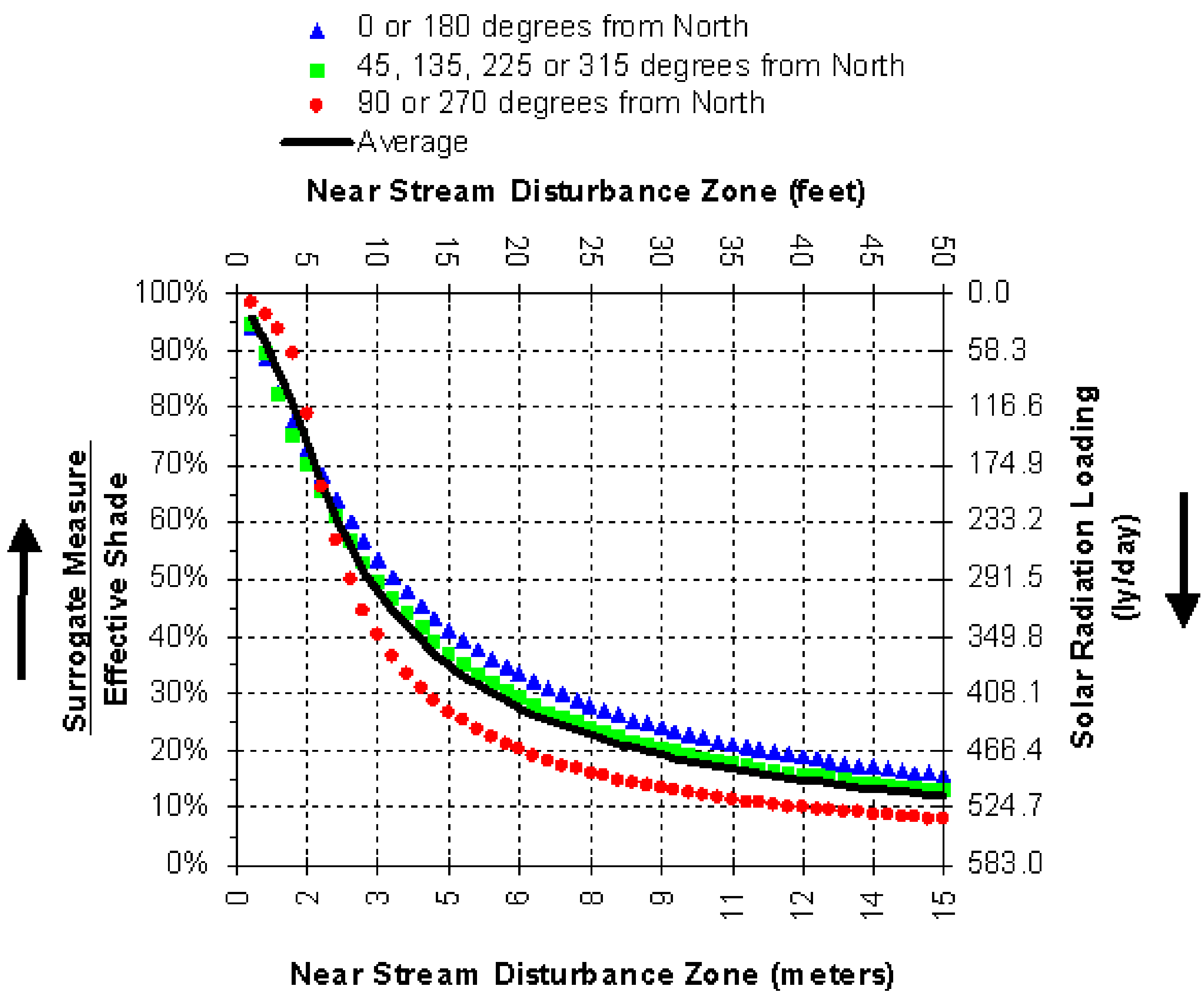


Figure 8. Effective Shade Curve – Application in Meadow Habitat Type – Tufted Hairgrass

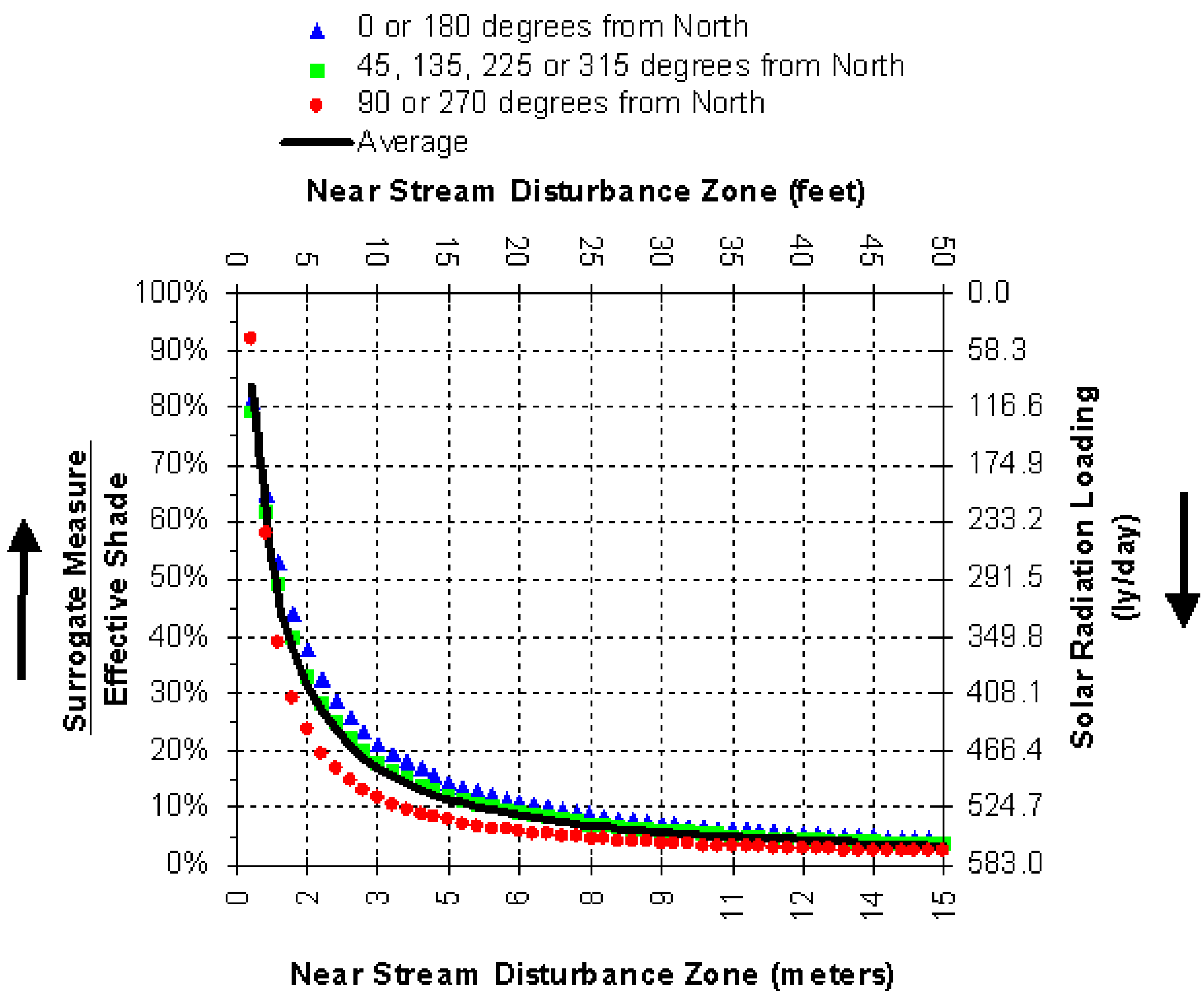


Figure 9. Effective Shade Curve – Application in Douglas Fir / Red-osier Dogwood Habitat Type

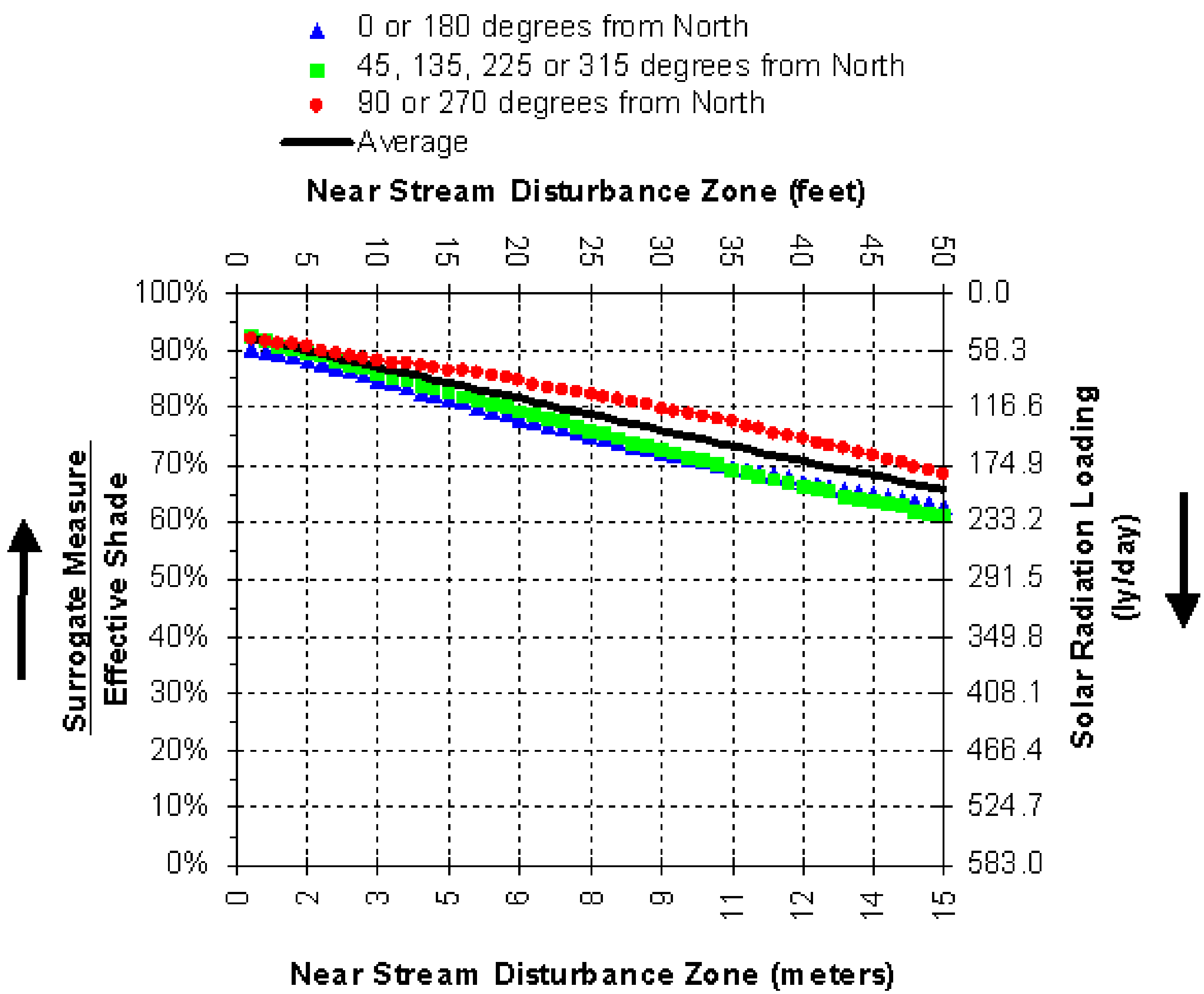
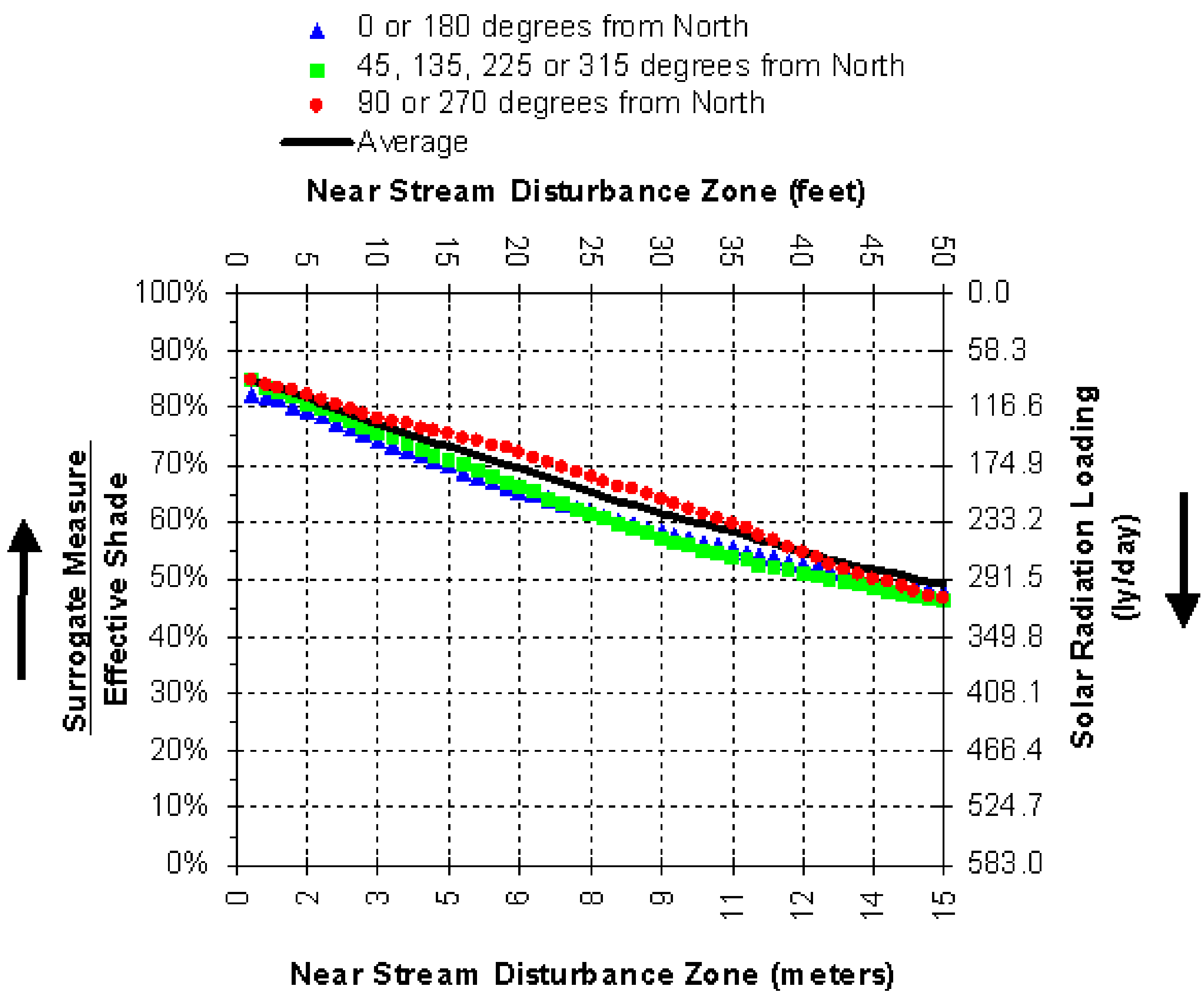


Figure 10. Effective Shade Curve – Application in Ponderosa Pine/Common Chokecherry Habitat Type



Effective Shade and Temperature - Role of Local Condition

The local features affect the potential effective shade conditions along a stream. Along with the channel and vegetation features (illustrated above), local geographic features affect the potential stream shade conditions. For example, stream elevation is used for calculating solar radiation loading and solar position. In addition, stream aspect and topographic shade partly determine the effectiveness of vegetation in providing shade to the stream surface. For these reasons, stream elevation, aspect and topographic shade angle were sampled for Crooked Creek from a 30-meter digital elevation models (DEMs) (see image to right) at 100 foot intervals. Sampling was accomplished using GIS tools developed for this specific application (www deq.state.or.us/wq /TMDLs/ WQAnalTools.htm). Sampling landscape features at a high resolution, from available data sets, enables a detailed evaluation of additional landscape conditions that, in addition to near stream vegetation conditions, may be influencing effective shade conditions along Crooked Creek, and ultimately affecting the temperature of the river. Both sampled elevation and gradient data are plotted for Crooked Creek in Figure 11. Topographic Shade Angles calculated from the DEM are presented in Figure 12. Stream Aspect is presented in Figure 13. Finally, stream valley bottom widths, defined as a maximum one meter elevation increase from the stream bottom (defined as a 1:24K stream layer), are presented in Figure 14.

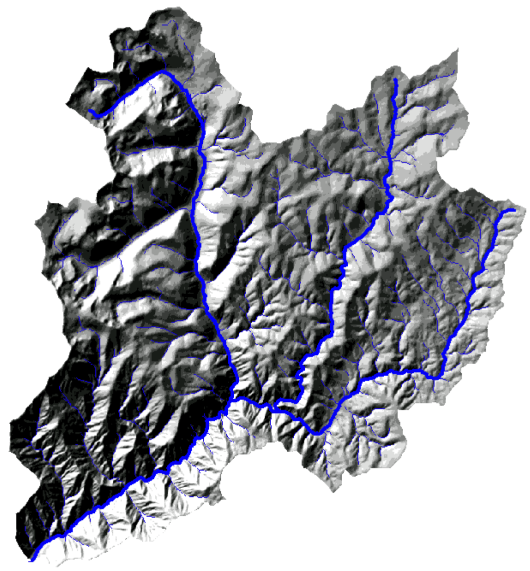


Figure 11. Stream Elevation and Stream Gradient along Crooked Creek.

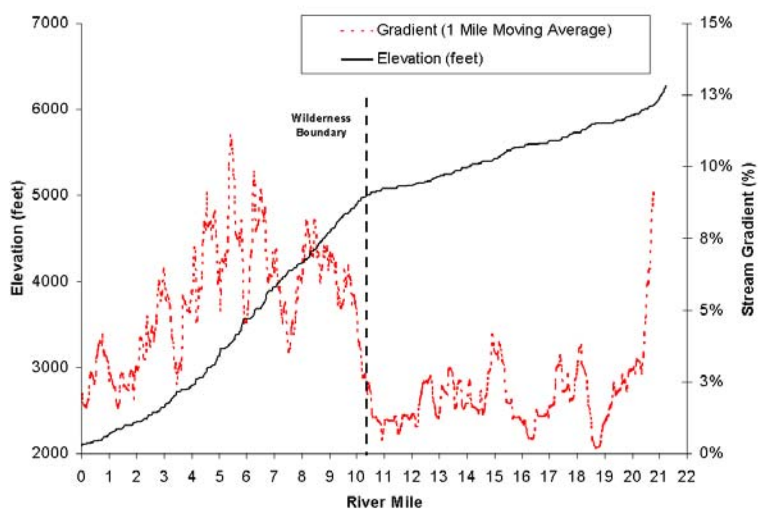


Figure 12. Topographic Shade Angle along Crooked Creek.

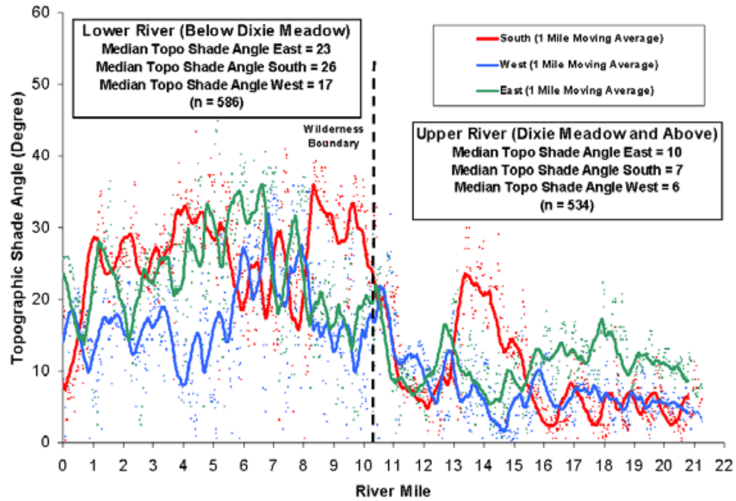


Figure 13. Stream Aspect along Crooked Creek.

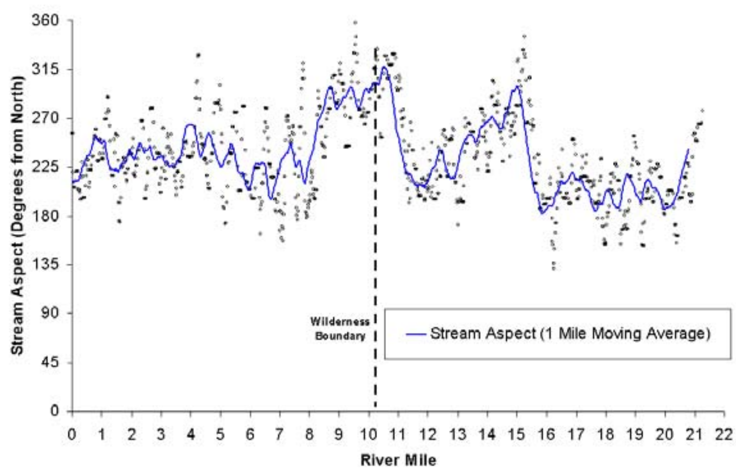
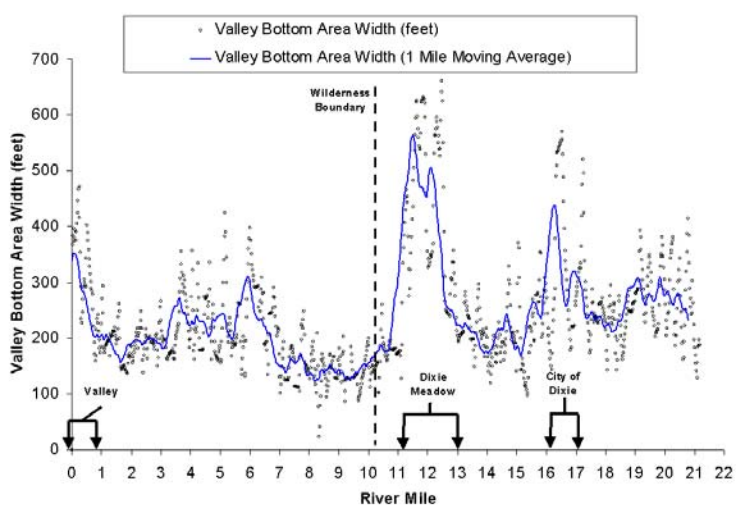


Figure 14. Valley Bottom Width along Crooked Creek.



These figures illustrate that Crooked Creek travels through several distinct areas, from upper reaches that experience relatively low gradients and topographic angles, downstream to an area with very high gradients and topographic angles. In addition, the upper reaches of the river travel through areas that are much less confined than in the lower reaches of the river (as defined by the rough estimates of valley bottom width illustrated in Figure14). This is especially evident within Dixie Meadow. All of these factors will affect the ability of the near stream vegetation to provide shade to the river, as well as determine the particular water temperature response from the energy balance affecting the river.

Estimate of Effective Shade Along Crooked Creek

An estimation of effective shade conditions for Crooked Creek was developed using physical information illustrated above, along with detailed vegetation conditions presented in Table 24. It is important to note that the resulting effective shade profile developed from this effort utilize the same algorithms used to create the shade curves (Figures 5 though 10), however this effort will contain a spatial component.

Estimate of Bankfull Channel Width

The only factor **not** developed from the work presented above is channel width (i.e., NSDZ or Bankfull Width). Accordingly, this parameter must be estimated from available information. Leopold et. al (1964) proposed that channel width tends to increase linearly with increases in drainage area. Rosgen (1996) reported that bankfull width can be estimated as a function of width to depth ratio and cross-sectional area.

$$BFW = \sqrt{W:D \cdot A_{bf}}$$

Where: A_{bf} is the Bankfull Cross-Sectional Area (ft^2)
W:D is the width to depth ratio

Figure 15 illustrates the regional curve for bankfull cross-sectional area (A_{bf}) and drainage area (DA) in the Upper Salmon River Basin (USGS Professional Paper 870-A). As noted above, Crooked Creek was segmented by vegetation habitat types (see Table 2). GIS was used to calculate the upstream contributing area (DA) at the lower end of each of these unique habitat types (Figure 16). Upstream contributing areas between these locations were estimated through interpolation. Bankfull Cross-Sectional Area was then estimated using the relationship presented in Figure 15. Width to depth ratio values were assigned values derived from published ranges for level I stream types (Rosgen 1996). Target Bankfull Width values for each of these Rosgen Level I Stream Types were estimated using the equation listed above (Figure 17). Target values developed during this exercise were used to develop channel width conditions used in Effective Shade Calculations.

Level I Stream Type	Width to Depth (W:D)
A	8
B	19
C	30
D	N/A
E	7
F	28
G	8

Figure 15. Bankfull Cross-Sectional Area as a function of Drainage Area in the Upper Salmon River Basin, Idaho (Emmett, 1975)

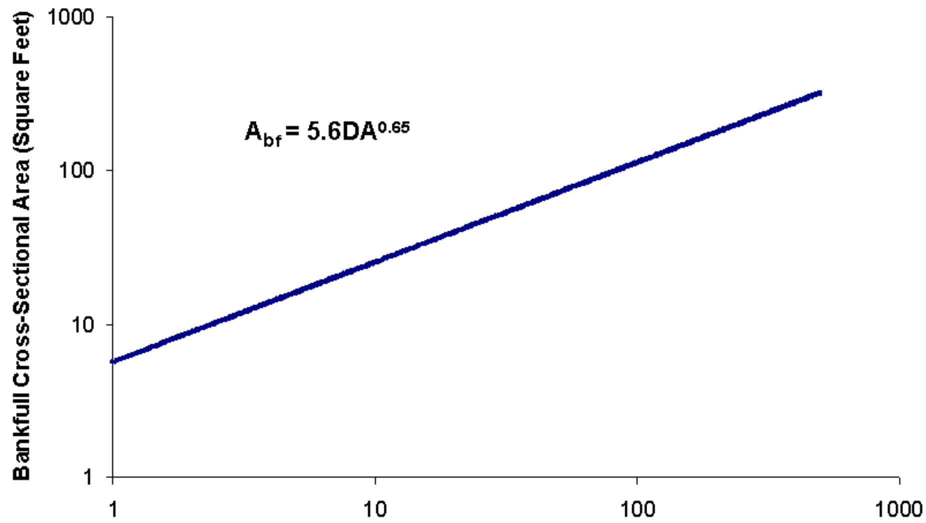


Figure 16. Upstream Contributing Areas within Crooked Creek

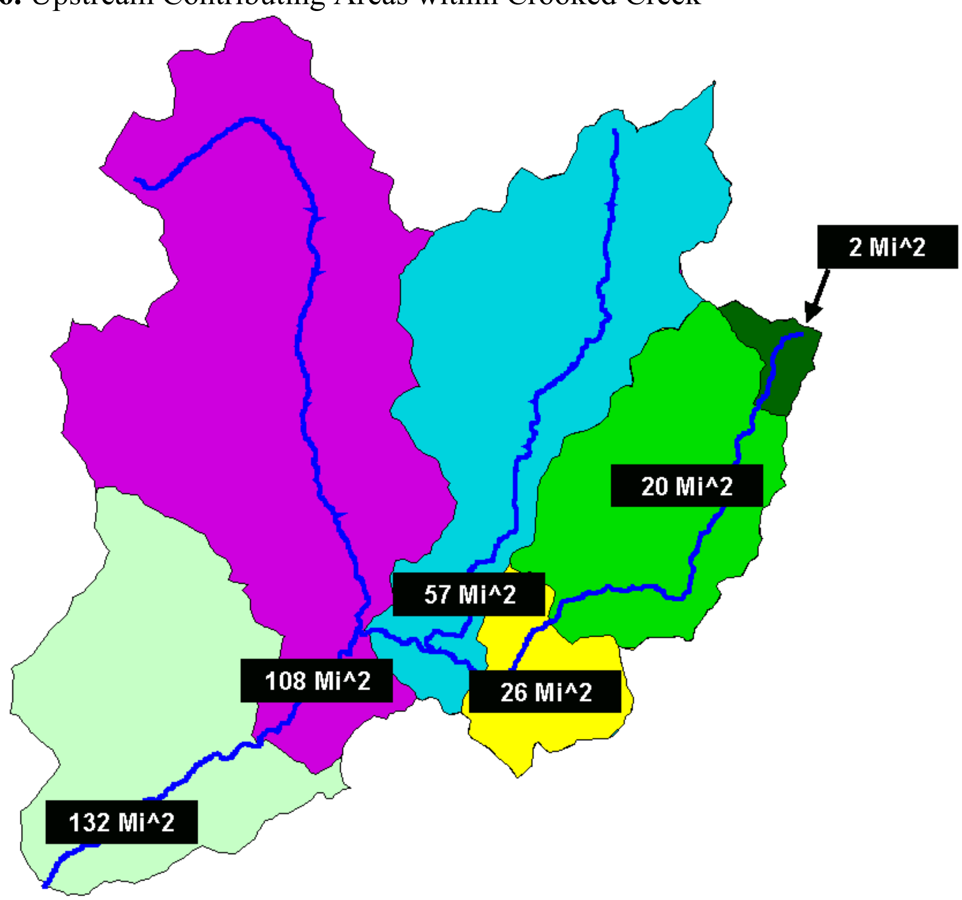
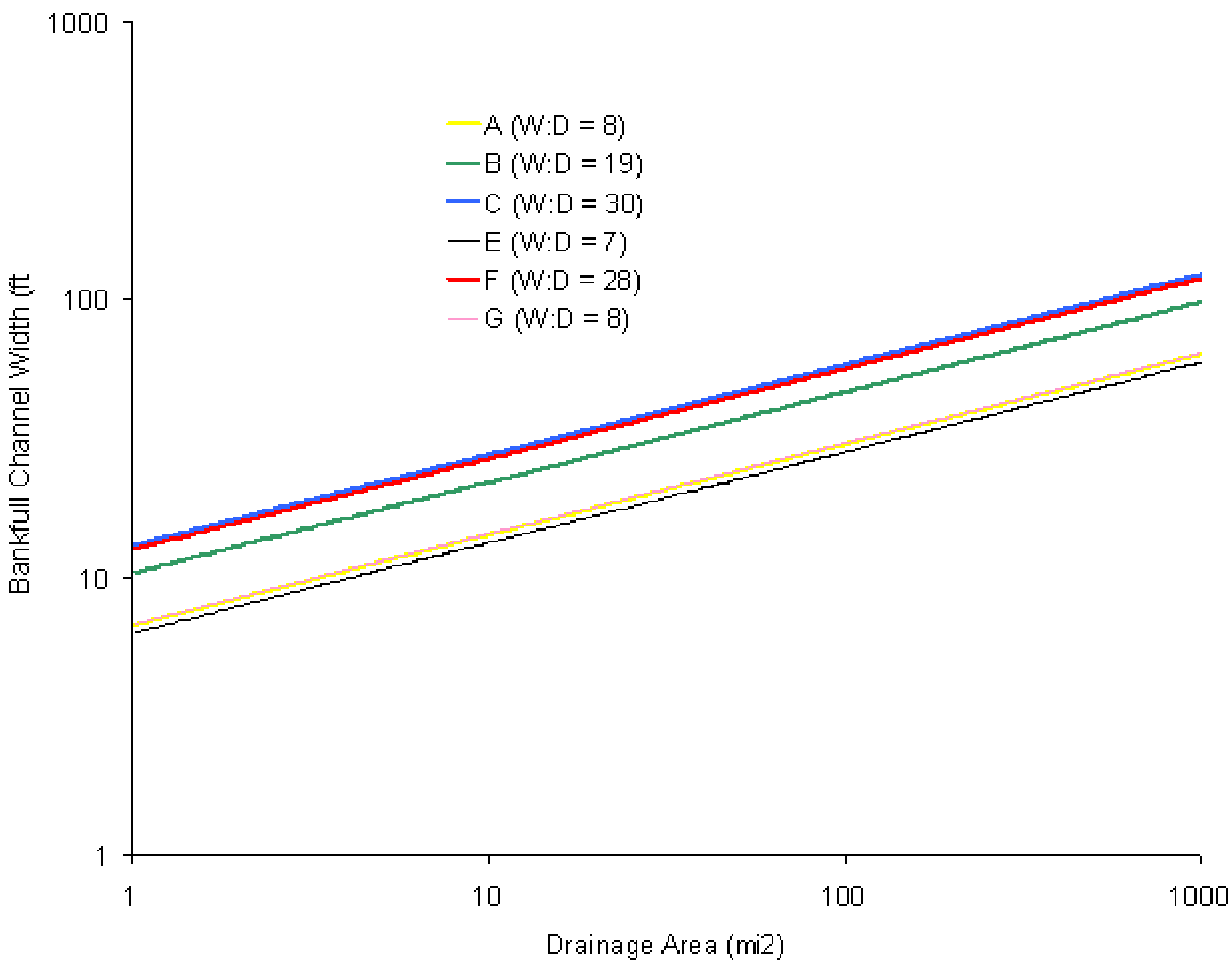


Figure 17. Bankfull Width as a Function of Width to Depth Ratio and Drainage Area



Accordingly, Rosgen level I classification can be used to estimate approximate bankfull width conditions through applying the equation listed above. Rough estimates of Rosgen level I classification for Crooked Creek were estimated from gradient information (Figure 11), and local knowledge. Figure 18 illustrates the approximate bankfull width conditions that would be expected as a potential condition along Crooked Creek. This information was used, along with aspect (Figure 13), topographic shade angle (Figure 14), and elevation (Figure 12) to calculate expected potential shade when applying vegetation communities along Crooked Creek (Table 24) (Figure 19).

Figure 18. Estimated Bankfull Widths in Crooked Creek

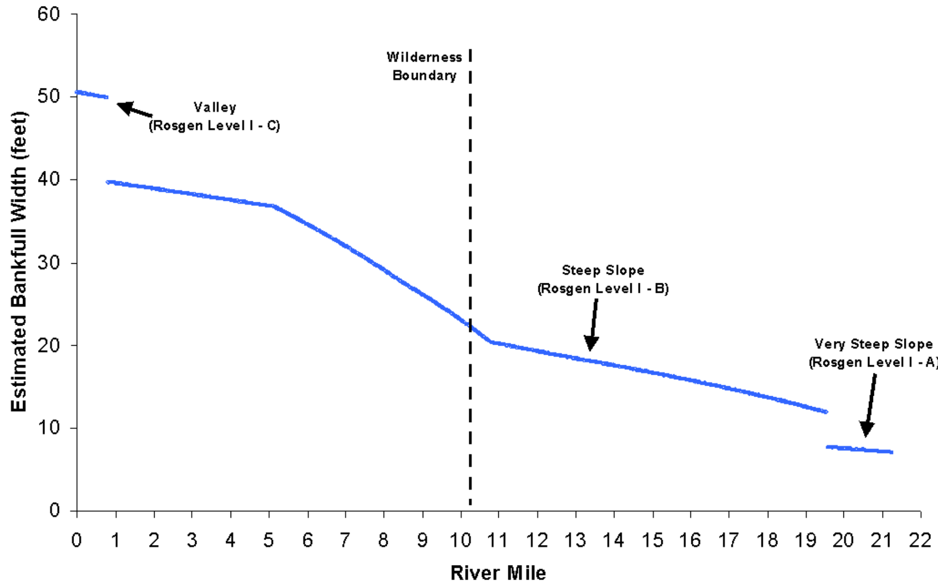
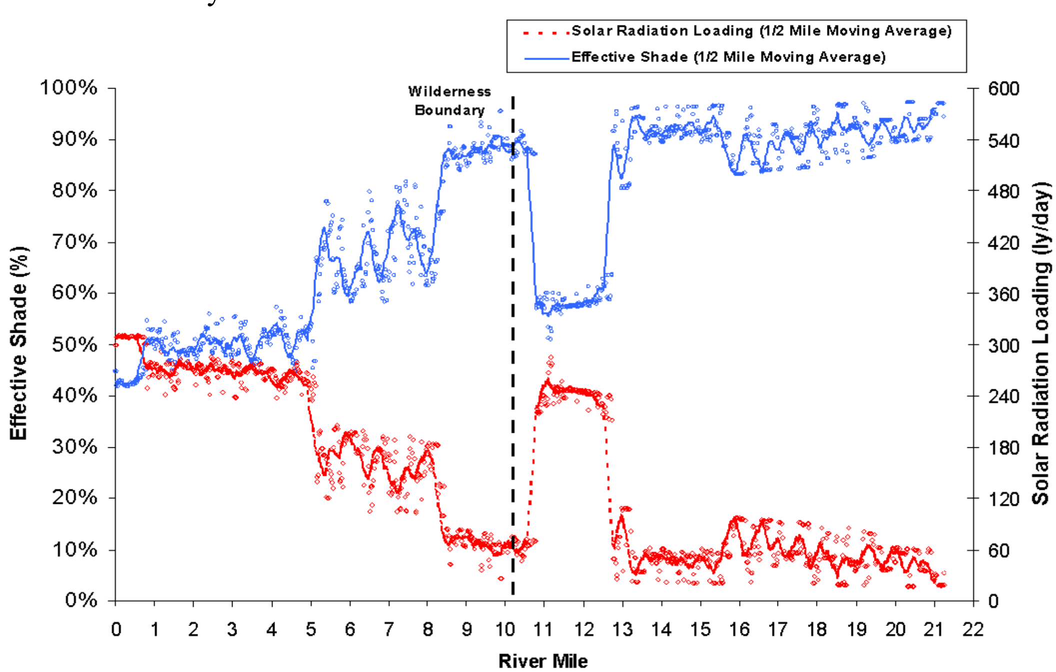


Figure 19. Estimated System Potential Effective Shade in Crooked Creek



LOADING CAPACITIES

Crooked Creek, as it advances down a steep canyon towards the Salmon River, becomes increasingly exposed to hotter, drier conditions and a change in vegetation communities from cold forests to dry forests, and eventually to shrub or grass dominated communities. Using the shade curves in combination with GIS-based local condition information, we have estimated the effective shade under potential natural vegetation to vary from approximately 95% in the headwaters to 40% at the mouth of the stream (Figure 19). The potential effective shade of 85 to 95% in the upper reaches coincides with communities dominated by cold forest conifers (subalpine fir and grand fir). In the lower half of the stream, forest community types are more typical of dry forests dominated by ponderosa pine and Douglas fir. Potential natural vegetation in the lower reaches has slightly lower effective shade from 50% to 80%. Additionally, the large meadow complex near the Dixie Work Center and airstrip would have an effective shade under potential natural vegetation (coyote willow meadow) of approximately 58%.

Figure 19 also presents the thermal loading to the stream under these effective shade scenarios. Thus, the loading capacity of the stream is represented by the red line in Figure 19, and varies from less than 60 Langleys/day in the headwaters to as much as 300 Langleys/day at the mouth of Crooked Creek in the Salmon River canyon. The meadow area near the airstrip and Dixie Work Center has a loading capacity of about 240 Langleys/day. As Crooked Creek turns southwest and begins its decent into the Salmon River canyon, the loading capacity decreases to 120 to 180 Langleys/day for several miles, then increases to 240 –300 Langleys/day.

WASTELOAD ALLOCATION

There are no permitted point sources within the Crooked Creek drainage, therefore there is no wasteload allocation for thermal loading to Crooked Creek.

LOAD ALLOCATION

Because the goal of this TMDL is to achieve a natural temperature regime to reduce stream temperatures as far as they will go, there is essentially no load allocation. The entire loading capacity of the stream is dedicated to achieving a natural condition as much as possible. Thus, the loading capacity presented in Figure 19 is equal to the natural background load. There is no thermal load that is dedicated to a nonpoint source activity.

TARGETS

To determine existing condition in the absence of solar pathfinder data, actual canopy coverage for Crooked Creek was visually estimated from 1996 aerial photographs at more or less 200-feet elevation intervals from the mouth to the headwaters. Table 25 shows these canopy estimates compared to those effective shade targets determined by the model. Unfortunately, stream segment intervals in Table 25 are not the same as river mile segments used in the effective shade modeling above. Rough comparisons to river mile are provided for some elevational intervals in Table 25.

Table 25. Canopy coverage estimates for 25 stream segments on Crooked Creek. The dashed line indicates the location of the Gospel Hump Wilderness boundary. (RM = river mile.)

Stream Segment Number	Approximate River Mile	Segment Lowest Elevation (feet)	Aerial Photo Existing Cover (%)	Potential Effective Shade (%)	Difference Between Existing and Target Cover (%)
1(Mouth)	RM 0	2080	50	50	0
2	RM 1.1	2200	40	50	10
3	RM 2.5	2400	40	50	10
4	RM 3.4	2600	40	50	10
5	RM 4	2800	20	50	30
6	RM 4.8	3000	20	50	30
7	RM 5.2	3200	40	60-75	20-35
8	RM 5.7	3400	30	60-75	30-45
9	RM 6.2	3600	30	60-75	30-45
10	RM 6.6	3800	30	60-75	30-45
11	RM 7	4000	50	60-75	10-25
12	RM 7.8	4200	50	60-75	10-25
13	RM 8.2	4400	50	60-75	10-25
14	RM 8.8	4600	50	80-90	30-40
15 (↑Wilderness↑)	RM 9.4	4800	60	80-90	20-30
16	RM10	5000	60	85-90	25-30
17	RM 10.6	5060	20	60	40*
18	RM 12.6	5200	40	60	20
19	RM 14.5	5400	50	90-95	40-45*
20	RM 15.7	5560	0	85-90	85-90*
21	RM 16.4	5600	20	85-90	65-70*
22	RM 18.2	5800	20	90-95	70-75*
23	RM 18.7	5840	60	90-95	30-35
24	RM 19.3	5880	70	90-95	20-25
25 (Headwaters)	RM 20	6000	70	90-95	20-25

*Problem Areas – those segments in need of the most rehabilitation.

To identify problem areas, the difference between the target effective shade and the existing stream canopy cover were examined. Although existing canopy cover estimated from aerial photos is not the same as effective shade, the difference between the two estimates serves as a screening tool for highlighting problem areas along the creek.

The areas in need of the most restoration of vegetation are based on the difference between these two percentages. The larger the difference, the greater the need for restoration. Increases in riparian and valley canopy cover should have a concomitant increase in effective shade and a decrease in solar radiation loading consistent with the model, and thus, a decrease in water temperature. This is a crude estimate of problem areas. In order to be more accurate, current effective shade should be measured in the field. Headwaters of Crooked Creek (above Dixie) shows a difference in values from 20 to 35. Further down stream, the difference between target effective shade values and existing cover in the upper segments (Dixie to the meadow), those most impacted by legacy mining and current development, are from 40 to 90. In the meadow itself, the difference is 40 assuming coyote willow returned to its full potential. Wilderness area segments (middle and lower) show a 10 to 45 range in value differences.

In addition to areas with reduced canopy coverage, Crooked Creek likely has an increased width-to-depth ratio as a result of dredge mining rearranging the stream, increased hydraulic loading, and posibbly other riparian activities that have lead to downcutting and widening of the channel. Figure 18 suggests that for this size of stream, bankfull width should vary from less than 10 feet wide in the headwaters (Rosgen Level 1-A) to approximately 20 feet wide before the wilderness boundary (Rosgen Level 1-B. DEQ has measured bankfull width of Crooked Creek at two locations within this upper half of the stream. The first site near RM 14 had an average bankfull width of 21 feet (based on three transects). This value is near the normal bankfull width of 18 feet predicted by Figure 18. However, the second site near RM 11 had an average bankfull width of 32 feet, a third greater than the predicted 20 feet wide in Figure 18. Bankfull width data collected by the Forest Service showed widths averaging less than 5 feet above the town of Dixie, 18 feet below Dixie, and 62 feet near the mouth. Of these three, the latter two (18 and 62 feet) are slightly elevated. These data, although limited, suggest that perhaps the stream widens a little too much through the large meadow near the airstrip. Maintaining or reducing bankfull widths to be consistent with Figure 18 may also prove usefull in reducing heat loads to the stream..

Canopy cover and bankfull width data suggest that the area in need of the most improvement in effective shade and channel dimensions is that area from the bottom of Dixie Meadow (RM 11) to about Nugget Gulch (RM 17), where differences between potential effective shade and existing canopy cover are greater than a value of 40.

MARGIN OF SAFETY

The margin of safety in this TMDL is implicit in the development of the potential effective shade. Effective shade is based on the hypothesis that the stream will experience a complete potential natural vegetal community along its borders all of the time. In reality, plant communities vary considerably with time as a result of natural disturbance (fire) and differential growth rates of species. To a certain extent, that is evident in the comparison of existing canopy coverage and the effective shade target for the wilderness section of Crooked Creek. Portions of this section have been exposed to wildfire in the recent past, probably resulting in less cover than is possible under potential natural vegetation. Nevertheless, there may be no greater margin of safety than achieving natural conditions.

SEASONAL VARIATION AND CRITICAL TIME PERIODS

Temperature criteria are applied to different time periods due to differences in life histories of target species and different regulatory conventions. The target species in this analysis has been spawning and rearing salmonids, especially bull trout. The spring salmonid spawning period ends July 15th, and the fall spawning period begins September 1st. These spawning periods often provide more than adequate time for spawning to actually occur. The federal bull trout criterion

(10^{o}C MWMT) applies during the summer months from June 1st to September 30th. Therefore, one of the lowest criteria is applied to the creek during the hottest time of the year. Considering the fact that potential natural vegetation estimations include deciduous species as well as conifers, the effective shade calculation targets the summer time period when the canopy should be at its greatest extent.

Climatic conditions vary from year to year. This variation is evidenced in the stream temperature data described above (Table 17 and 18). For example, 1994 seemed to have the highest temperature statistics and 1995 had the lowest. In Table 18, the number of days exceeding the federal bull trout criterion varies from a low of 229 days in 1997 to a high of 319 days in 1998, almost a 30% difference. The target effective shade should be consistent from year to year despite changes in climate from year to year. The majority of plant species considered are either long lived or receive their watering needs from the stream itself. The meadow is one area that may have its canopy cover more affected by drought conditions than other habitat types.

Future Implementation

The increase in stream shading specified herein will improve (reduce) water temperatures. The analysis conducted provides our best estimate, with given information and resources, of the extent to which stream temperatures can be improved through increased shading. There remains uncertainty as to whether current temperature criteria can be met throughout the length of this stream. Upon implementation of shading improvements, including possible ancillary improvements in channel dimensions and floodplain connectivity as a result of actions taken to increase shade, an evaluation will be needed of other possible actions to meet the true thermal potential of this stream.

It is important that a long-term goal of achieving potential effective shade be realized through resource management objectives. Differences between the potential effective shade and the existing cover vary from 0% to 90%, although for the majority of the stream the difference is less than 40%. All but one stream segment had less existing vegetative cover than effective shade based on potential natural vegetation (Table 25). Differences found within the wilderness area are probably the result of wildfire and to a lesser extent legacy activities. In the upper reaches of Crooked Creek, major differences (70 - 95%) occur between existing cover and potential effective shade, an area roughly corresponding to the reaches between Horse Flat Creek and the cemetery below Blane Creek.

Given the nature of the environment around upper Crooked Creek after a century of placer, dredge and lode mining, it is very unlikely that canopy coverage can be increased to such high levels without a tremendous amount of expense and time. The stream system for at least four miles would need to be rehabilitated including the creation of proper channel dynamics (including width-to-depth ratio), the addition of topsoil, and the planting of vegetation.

We recommend the land owners (Forest Service and private) attempt any reasonable effort to affect temperature in Crooked Creek including decreasing width-to-depth ratio in the stream where possible, revegetation where possible, and the control of activities likely to affect vegetative cover and channel characteristics. We also encourage the Forest Service to continue to monitor stream temperatures to see what temperature reductions are achieved, to measure existing effective shade through the use of solar pathfinders, and to take additional channel width measurements (especially where shade is measured).

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APPENDICES